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INDUSTRIAL SCIENCE
PRESENT AND FUTURE

A collection of papers presented at the installation of the
Section on Industrial Science of the AAAS at the Philadelphia
meeting on December 28–30, 1951

Arranged by
ALLEN T. BONNELL
Vice President, Drexel Institute of Technology

Edited by
RUTH C. CHRISTMAN

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Foreword

There was a time when the phrase "industrial science" might have been regarded as a contradiction in terms, for it was not too long ago that science was not industrial—and industry was certainly far from scientific. Today the words "science" and "technology" are spoken almost in one breath; their alliance is so generally accepted and mutually profitable that, in everyday speech, we often fail to make a distinction between the two. The phrase "industrial science" relieves us of an ordeal in semantics and permits us to recognize frankly that every enterprise in science is of practical significance in our economy and through our economy to the general welfare of each individual.

Papers printed in this volume were presented at the sessions marking the installation, at the 1951 Meeting of the American Association for the Advancement of Science (Philadelphia), of a Section P, Industrial Science. Installation of such a Section at the 118th Meeting of the Association since its founding in 1848 did not imply a first exposure to, or interest in, industrial science. It was merely acceptance of the *fait accompli*—recognition of the fact that throughout the disciplines represented in the Association considerable attention was being addressed to the industrial application of scientific discoveries. To be sure, this was not an unrequited interest, for industrial management had demonstrated an increasing respect for the products of "pure" research and an inclination to devote increasing sums of money to industrial research. It had demonstrated also a keen interest in the application of the methods of science to industrial management.

The stated purpose of the new Section is threefold: first, to advance the knowledge and application of science in industry; second, to further the interests and status of scientists engaged in research, education, or other work relating to the development, application, and use of scientific principles and knowledge to problems of industrial operation and management; and third, to promote public understanding and appreciation of the importance and promise of industrial science in human progress and welfare.

These objectives are to be pursued by encouraging and promoting a freer interchange of ideas and knowledge among those engaged in theoretical and fundamental sciences and education, on one hand, and those engaged in applied or industrial science on the other. Indeed, there will be more than an attempt to promote an exchange of ideas between the pure scientists and the men of industry. There will be an effort to expand the exchange of ideas and knowledge among individual scientists. In a few of the scientific disciplines industry now claims as many graduates of our colleges and universities as education and government combined. There has been a tendency on the part of many of these specialists attached to industry to maintain their specific scientific nomenclature. Some continue to insist that they are industrial *chemists*, or economic *entomologists*, or petroleum *geologists*. Despite their intimate association with industry they have failed to recognize the significance of the industrial ties that bind them in a common fraternity. There are still some chemists who insist that they are chemists, and geologists who still insist that they are geologists, with as much finality as "pigs is pigs." It is the thought of the Association that the newly established Section on Industrial Science will provide an acceptable and challenging common denominator for all scientific disciplines.

Initiative for the activation of the Section on Industrial Science was given by the American Industrial Hygiene Association when it became affiliated with the AAAS in 1950. Its officers asked for the creation of a separate section that might encompass the varied, yet closely integrated, field interests of such a group. The Association, recognizing the value of a new section that would serve as an integrating force within the organization, placed the matter to a vote of the AAAS Council. An overwhelming majority favored the establishment of a Section on Industrial Science. It was felt that the strength of such a group would come not only from among the older AAAS members, but also from the staffs of the industrial research laboratories and from other professional groups interested both in an exchange of ideas on the technical aspects of industry but in such things as the problems of management, financial support of research, team research, access to technical communications, instrumentation, and all of those problems of organization and operation that confront scientists who are applying discoveries and methods to industrial operations and products.

Organizational affiliates of the Section on Industrial Science now include the American Industrial Hygiene Association, the Society for Industrial Microbiology, the Southern Association of Science and Industry, Inc., and the American Society of Safety Engineers.

ALLEN T. BONNELL
Program Chairman
Section P

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Bridging the Gap

EDWARD R. WEIDLEIN

President, Mellon Institute of Industrial Research, Pittsburgh, Pennsylvania

I FEEL highly honored to have a part in the installation of a Section of the American Association for the Advancement of Science which deals with industrial science, for I have devoted my life to the application of science for the benefit of mankind. I am happy to see the AAAS recognizes that university scientists and industrial scientists have mutual interests, that one group supplements the other, and that they will be brought together at future meetings. Both will benefit greatly by such contacts. This Section should develop into one of the largest and most interesting divisions of the Association.

GROWTH OF APPLIED SCIENCE RESEARCH

Why has it become difficult without a knowledge of science to do many things or to understand many things that are happening in finance, industry, and commerce, and even in diplomacy and politics? What is this ever present science for which so many leaders in business cherish an attachment? Science is important and admired because it has succeeded in organizing, managing, and advancing both the industries and commerce; because it does not live on the glories of the past; because it does not tear down, but, on the contrary, has discovered how to build.

Industrial science—scientific management in the industries and its fact-finding agency, industrial research—occupies a prominent position in the business world. This applied science scintillates with splendid achievement, but in the background is the pure science that is essential for its progress.

In 1789 the American Philosophical Society made the first organized effort to encourage scientific research on behalf of our nation. In his annual address the following year President Washington said, "There is nothing which can better deserve patronage than the promotion of science." Subsequently the sentiment grew that the support of natural science would contribute to the welfare and security of the country. There evolved a great capacity for adaptation, a persistent willingness to meet new conditions with new methods, and a remarkable creativeness that have produced the American tradition of natural science research.

The scientific knowledge which has made possible modern industry was acquired slowly, for the most part in the universities of the world, by men who were stimulated by curiosity and who made discoveries for the joy of it. The students who at first worked in these scientific fields were led to do so mainly through the influence of their teachers, for there was little general recognition of the industrial value of science. The industries later discovered, however, that men who had been trained in the fundamental sciences, such as chemistry, physics, and mathematics, were particularly useful, because they understood better the nature of industrial processes.

Until about 1900 there were almost no industrial research laboratories, and industrial applications of science usually originated from individual inventors or from engineers or scientifically trained men in factories. Then, during the first decade of this century, several large companies established research laboratories for the purpose of applying scientific principles to the development of new products and processes.

The Stimulus of War

The growth of scientific research in the United States received its first big impetus as a result of our experience in World War I. Prior to that time research sponsored by the industries and by the federal government was usually directed toward the solution of practical problems; comparatively little of it was devoted to the quest for fundamental principles. The extent to which our basic scientific knowledge grew between 1918 and the end of World War II was impressive, and no evidence could be more weighty than that proceeding from the synthetic rubber and atomic bomb projects. We can easily visualize the weak position in which America would have been placed during World War II if science and industry had not carried out broad research and development programs between the wars. Accelerated wartime research brought about many notable advances, but these would not have been possible except for the scientific alertness of American industry and the technological achievements of the twenties and thirties.

Other Stimuli

Several circumstances aside from the influences of two world wars have stimulated the great growth of industrial research in the United States. Much of the American industrial domain developed after it had become generally clear that the forward movement of technology was dependent upon the application of scientific knowledge. The definite cleavage between pure research and industrial research took place at the inception of that era, forty years ago. The success of industrial research under the aegis of the university, as demonstrated by Robert Kennedy Duncan, founder of the Industrial Fellowship System under which Mellon Institute operates, gave deep-seated impetus to this research in general and to its application and organization in technology in particular. As soon as American industries started on their rapid expansion, academic scientists, sympathetic toward technology, were in demand. In consequence close contact and mutual appreciation were established between industrialists and applied scientists in universities.

Courses in engineering and industrial chemistry and also the consulting work of faculty members and the setting up of fellowships all encouraged these advantageous relations. Many young men specializing in science, following the lead of engineers, became desirous of securing industrial positions, and as they succeeded in doing so and subsequently obtained wider opportunities and responsibilities, they in turn broadened the future scope for those with similar training who came afterward. The effect has been cumulative, and both technology and education have benefited to a high degree from the gradually acquired prestige of science in industrial management. The mighty sway of industrial science and research will become more inclusive, more generative, with the further availability of suitably trained men having the right qualities for investigation and its administration.

About fifteen years ago industrial research reached a robust stage of maturity when, in its fold, biology, physics, and mathematics joined chemistry, chemical engineering, ceramics, and metallurgy. Since then it has become usual for company presidents to give space to research in their annual reports. This research is very ramified, extending everywhere and touching everything in the manufactures. Whatever happens to technology affects all of us.

INDUSTRIAL RESEARCH BY FELLOWSHIPS

Fellowships maintained in research institutions by companies are usually concerned with basic applications of science, with laying or completing the scientific groundwork of technology. Their motives are utilitarian, but, as theory and practice are closely interdependent, long-range industrial research programs also embrace well-indicated theoretical studies. Such comprehensive scientific investigations for the industries show ways for the attainment of production, novelty, and quality that afford satisfaction and certainty in manufacturing and marketing. Consequently institutional industrial investigation, in supplement to company laboratory work, is being brought to bear on a very broad technologic front to meet the persistent demands of change and improvement by giving rise to useful results and to fresh forms in research and development procedures. From such programs have come abundant industrial, communal, and professional benefits.

The consistency and propriety of this aid are seen in the accepted dictum that the university stands for the whole good of man, for the uplift of man. The absolute function of the university is not only the increase and diffusion of knowledge among men but also of useful knowledge. It must be remembered that it is only through useful knowledge that the people have gained the material blessings of our civilization. Furthermore, it must be remembered that every useful agent in our civilization is the product of our industry and that it is only through the industries that these new products of civilization can go to the people. Every discovery utilizable by industry is a thread in the fabric of a future and more gracious civilization.

Systematic programs of industrial research are of a practical nature and are geared to the requirements of industry. Hence these investigations have led to many new processes, products, and manufactures. Industrial research must continually keep near to companies that are being helped on their problems. As needful, there are research projects involving the work of specialists in two or more branches of science. Outstanding have been joint investigations by chemical and biological scientists, by physical and ceramic researchists, by engineers and hygienists, by metallurgists and chemists. The sciences are becoming more and more interrelated. Every science not only makes advances in its own realm, but it also furnishes means by which progress is made in other fields.

In bridging the gap we must not forget that the applied sciences owe much to the pure sciences in which knowledge is pursued for its own sake, just as the pure sciences owe a great debt to the applied sciences. We have been reducing our fundamental supply of information just as much as we have been exhausting our great natural resources. Fortunately this situation is becoming more generally recognized by industry, and as a result we can look forward to a more concrete form of support for scientific departments in our universities by industries in order to create this new knowledge and better to train our scientific personnel for industrial research. Thus industry will make a far-reaching contribution to the educational world.

The invigorating views of many industrialists regarding the proper spheres of the sciences, in and through research, have already been manifest in their continuous encouragement and aid. Also constantly evident is the friendly nearness of the whole of education to all that belongs to this research.

To achieve mastery of major national problems, our research agencies must make strides assisting social science to a place beside natural science, principally by infusing methods of the latter. All science is sensitive to societal changes around it, and in peacetime science is always productive of good. Scientists can assist in defining conditions that nurture peace; they can benefit humanity on cultural as well as material levels. The characteristic spirit of science is service to society—a mental attitude that is open, willing to face the truth, humanitarian, and objective, and that is flexible, not fixed in pattern, but capable of brisk adjustment to meet changing conditions.

Accordingly the natural scientist should be imbued with a high appreciation of the value of human relations in his domain and in education for it. Scientific research management means to be not only a system of administrative practice and teaching, but also, in vital union therewith, a system of revealing facts respecting the nature of scientific investigation and its relationship to the human race. In consequence it is only to be expected that alert research executives are devoting more and more attention to the influences of human relations on the efficiency and well-being of their organizations.

In the realm of human relations a beneficial return from the war is the occasional intermingling of the natural and social sciences. Cross-fertilization ensues that induces new thinking about fundamentals, systematic use of ideas, and practical teamwork. Natural and social scientists can indeed cooperate in increasing the capacity of people to satisfy their wants and in developing new forms of control over social conditions and forces. Solid economic and societal progress will depend more and more upon such firm correlation and mutual effort. The infusion into industrial management of a realization of the essentiality of happy human relations will flourish in the climate of this joint scientific support. Scientists with fresh ideas and the desire to put them to test are welcome in the world of affairs as never before. The human race is growing at the rate of 200 million persons a decade, and every nation is a proving ground for appraising substantial proposals for the pilotage of society.

Mellon Institute has found, especially in its active participation in community development, that many data useful for social science research can be derived from its long natural science research experience. The Institute has therefore been able to assist collaboratively in vitalizing social science through investigations in human relations. Studies of human relations in industrial management have shown they can better the development of leadership, healthy environment, morale, capacity for cooperation, psychology of selection and participation, and community service. War demonstrated that no nation is stronger than its science and industry, that no science and industry are stronger than their manpower. Industrial laboratories, plants, processes, and machines of the future will be designed with more and more appreciation of the importance of the human factors.

To serve best in the changeable world of today scientists must adapt themselves to the effects of this very time. Laymen have a fairly clear comprehension of the import of scientific research, and hence scientists have recognition as a necessary and unique group in the population. Organizational forms under which essential investigational work for the most part will subsequently be conducted will no doubt be broader and farther reaching than practices of the past, and it is hoped that every area where scientific methods can enhance man's understanding of himself and his surroundings will be systematically explored. In the disciplines befitting peace, however, science that can forward our welfare must have the stimulating zest of the reality of unrestraint: it must be free to thrive, to educate, to venture through research into new paths. With this freedom science can give invaluable help in guiding the stream of history.

PERSONNEL NEEDS OF RESEARCH

For many years the objective in natural science has been to strengthen and to demonstrate the utility of research. This purpose connotes not only the encouragement of excellent standards in investigational work, but also the creation of new opportunities and responsibilities for professional development. Institutions, governmental agencies, and industries are unceasingly on the quest for able researchists. Research-minded organizations have set criteria for evaluating promising research projects and their supervision and have emphasized systematic classification in the selection, motivation, and development of personnel for these investigations. Thus has come an understanding of the requirements of management and of the training of scientists for executive posts.

Science has so much to think about and to do that every auxiliary must be exerted to urge on its votaries and to train adequately all the promising young persons who can be drawn into and kept in its field. Working together, many organizations are trying to meet this educational need in science. It is plain that there must be a continuous flow of newly trained scientists and new scientific data from the universities. Life and vigor must therefore be instilled anew into graduate scientific education so as to restore to freshness and fruitfulness the sources of the stream of research.

As is now clear to all in science, although the quantity of research services is much less important to human welfare than the quality of such services, the problems of research personnel management are quantitative as well as qualitative. Hence the personnel needs of research are dependent upon education. In research management there should be a fourfold interest in the educational aspects of the field: first, to lay open the meaning of such scientific work; secondly, to assist in effecting improvements in the power of teaching for investigational careers, especially by cooperating with universities and professional societies; thirdly, to better procedures of attracting more capable students into training for research; and, fourthly, to encourage junior personnel to pursue graduate courses wherever possible. High importance must be attached to the well-trained scientist by giving him careful direction and ample facilities. Also, there must be stressed the cheerful phases of personnel behavior, the factors that render researchists contented as well as successful.

The roots of collaboration are deep in the general welfare of all science. Where well-composed cooperation prevails in a research institution, every scientist there is encouraged not only to make advances in his own field but also to help in supplying technical means by which, through adaptation, forward strides are brought about in other sectors of scientific investigation, and to have a voice in conducting the professional life of all the personnel. If there are many different research undertakings, diversity can be held together by a clear conception of common interests and obligations. Properly nourished specialization fertilizes every branch of science, every variety of scientific research. The future of all parts of the realms of science and technology therefore depends upon the development and work of sufficient specialists. But to be able to contribute most effectively to making better things for a better world these specialists must learn about other segments of science and about human affairs as these subjects connect with their own fields of investigation. Careers in scientific research as well as in its managements should be made as full, as useful, and as attractive as possible.

In all scientific research, ideals, ideas, and projects must be shaped so that they correspond to reality, to the actual environment, to the needs of the people. Research must measure values in terms of human benefit and permanent stewardship—a fact that is recognized by the numerous companies that carry on scientific investigation.

INDUSTRIAL SCIENCE TODAY

The Petroleum Industry

ROBERT E. WILSON

Chairman of the Board, Standard Oil Company (Indiana)
Chicago, Illinois

INDUSTRIAL science on any worth-while scale is a relatively new activity. As an aid to visualizing the situation, suppose we compress the 500,000-year lifetime of the human race into 50 years. Using this compressed time scale, we find that man did not become smart until rather late in life. It took him 49 years to get over being a nomad and to settle down in organized communities. It took him even longer to get his first pair of pants and many of the other things we consider to be time-worn characteristics of man. About six months ago a few men first learned to write; two weeks ago the first printing press was built. Only within the last three or four days have we really understood how to use electricity, around which so much of modern civilization is built!

And within the very last day have come such amazing things as radio, television, diesel locomotives, rayon, nylon, sulfa drugs, penicillin, electric computers of complex equations, 100-octane gasoline, color and sound in motion pictures, and hundreds of other things we take for granted. Jet planes, a dozen new antibiotics and hormones, and the release of atomic energy all came into the picture while we were getting up this morning.

The oil industry itself entered the scene only recently. On our compressed time scale the oil business came into existence last

Tuesday, but didn't get around to doing research until very late on Thursday!

ACHIEVEMENTS OF PETROLEUM RESEARCH

In spite of its late start, petroleum research, like research in so many other fields, has many achievements to its credit. To summarize a few:

1. The yield of gasoline from crude oil has more than doubled, and could readily be quadrupled were it not for the growing need for heating oils, diesel fuels, etc.

2. The average octane rating of motor gasoline has increased to the point where one gallon of today's gasoline—in an engine designed to utilize it effectively—will do the work of two gallons of 1920 gasoline.

3. Today's piston engine for aircraft will produce over ten times as much power, with half the weight per horsepower, as the best engines used in World War I. Although engine research and metallurgical research have helped substantially, the tremendous improvements in aviation gasolines and lubricating oils have been the major factors in this result.

4. In spite of the improvement in quality, the price of gasoline (excluding taxes) since World War II has been so low that it represents a saving to the public of over four billion dollars per year as compared with the 1920 price! Relatively speaking, gasoline is the cheapest commodity on the market today.

5. Although oil is gradually becoming harder to find and although consumption is increasing, many new methods of exploration have enabled us to find oil faster than we have used it. Drilling and production methods have also been greatly improved. The nation's proved reserves of crude oil are at an all-time high.

6. The energy consumption of this country has increased enormously in the past half-century. Since 1918, when the effects of oil research really began to be felt, usage of petroleum and natural gas has increased more than sevenfold, while coal has actually slipped back a little in total output. Liquid fuels from petroleum not only drive our highway and rail vehicles, but also heat homes and furnish power for farm machinery that enables one farm worker to grow the food that formerly required three.

7. In spite of the fact that the hydrocarbons ordinarily found in crude petroleum are notoriously unreactive, over 90 per cent of the molecules in today's military aviation gasoline are not found in the crude, but are made by synthetic chemical processes. Even motor gasoline usually contains about 60 per cent of synthetic molecules. Petroleum refining has become in large part a chemical-synthesis industry. The magnitude of its operations dwarfs all the synthetic processes and products of the "old line" chemical industry. The annual production of alkylate alone, at the wartime peak, amounted to more than fifteen billion pounds a year, or about twelve times the total present production (by both fermentation and synthesis) of ethyl alcohol, which used to be the largest volume organic chemical. And only fifteen years earlier both the process and product of alkylation were unknown!

8. New developments in hydrocarbon technology have made petroleum an increasingly important source of many vital chemicals formerly manufactured from other raw materials. Important products now made from petrolum include glycerine and various alcohols, glycols, and ketones; also acetic acid, nylon, synthetic rubber, toluene and, most recently, benzene itself, the starting point for a whole host of essential items.

9. Last, and most reassuring for the future, the industry has developed several processes by which liquid fuels can be made from coal or other non-petroleum sources, just as soon as there is economic justification for doing so.

The benefits of applied research to the industry and to the public have been so outstanding that the number of technically trained men engaged in research and development in our industry is at least forty times as large as in 1916. The annual expenditures are now in excess of $100 million per year. Although cost is a poor way of measuring the value of research, it does show management's confidence in its past and prospective worth.

HOW DID IT HAPPEN?

Both the growth of research in the petroleum industry and its achievements are phenomena that warrant analysis as to how it all happened. Yes, "happened" is the word, because in this industry it was definitely a gradual evolution and not the result of any long-range foresight or planning.

The great bulk of the applied petroleum research has been done in industry laboratories, and today fully 90 per cent of it is carried on by such competitive organizations. This active competition has been largely responsible for the development of dozens of valuable processes. Moreover, every process has been made more efficient with the passing years, as each operator has tried to gain a little advantage over his competitors in the economic race. While many of the steps have been small, the cumulative effects have been tremendous.

COMPETITIVE VERSUS COOPERATIVE RESEARCH

There are still a few in this country who argue that competitive research involves too much duplication of effort and waste of scientific manpower. Abroad, the opinion is rather widespread that the government or trade associations should carry out most applied research on a cooperative basis, in the expectation that this would reduce total research costs. But reduction in research costs should never be the main objective. The real question is, what would happen to the rate of progress?

Cooperative research suffers from the absence of an incentive to make a profit, to get ahead in the competitive struggle. It also abandons the proved advantages of many independent centers of initiative and different methods of attack. Furthermore, if duplication is really to be avoided, there would have to be centralized control.

It is hardly necessary to say that no individual, board, or bureaucratic organization is wise enough to administer such a setup. During World War II Germany had centralized control of research and failed to make good use of its outstanding scientific manpower, once the dictatorship attained full domination. By all logic Germany, with so many of the world's best scientists and a head start on the fundamental nuclear research, should have beaten the Allies to the atomic bomb. The postwar analysis of German wartime research showed that centralized control was its greatest weakness, especially in fields requiring real imagination and initiative. A sorry present-day example is the research being done by the Lysenko group in Russia—if the frantic hunt for evidence to support a false theory, dictated by politicians, can properly be called research.

On the other hand, even the strong advocates of competitive research realize that competition can be carried to extremes. If there were general unwillingness to publish results promptly, after they have been protected by patent applications, or to disclose and license new processes as soon as they are developed, scientific and industrial progress might be slowed down. As Kettering well said, whoever locks his laboratory door locks out much more than he locks in. Fortunately, the United States patent system encourages prompt disclosure and interchange of information, without jeopardizing the inventor's rights to his discoveries.

DEVELOPMENT OF CRACKING

It is difficult to philosophize about research in the abstract. The concrete example of the development of cracking in the oil industry illustrates many important points, and it has been duplicated in principle in many of the later advances in our industry.

The development of cracking furnished the main driving force for the tremendous expansion of oil research that took place after World War I. I shall review it, not so much from the technical viewpoint as to analyze the incentives and the far-reaching results.

The petroleum industry began with the Drake well in 1859 and had been in existence for thirty years before it made an appreciable attempt toward research on anything. There were several reasons for this. First, the chief competing industries were not exactly stiff competition. Whale oil and coal oil were inferior to kerosene as burning oils, and they were much more expensive. Secondly, Mr. Drake had been lucky enough to find, in the Pennsylvania fields, a crude that was not only relatively abundant but that is one of the easiest of all crudes to refine. Where there are few problems, there is little research.

So it was not until 1889 that the first highly trained chemist was hired in the petroleum industry. He was Dr. William M. Burton, just out of Johns Hopkins University. He was hired to help Standard Oil solve the problem of making marketable products from the recently discovered "sour" crude oil from Lima, Ohio. As usual, it took a tough problem to get research started, but once that difficulty was solved, no other serious scientific problem seemed to press for solution for some time.

Not until twenty years later, a full half-century after the start of the industry, did Dr. Burton initiate his pioneer work on cracking. By that time a few had begun to recognize the need for some method of increasing gasoline yields. If gasoline production were to remain at the 15 or 20 per cent that could be separated from the average crude oil by fractionation, the price of gasoline would soon go so high as to stifle the development of the automobile industry, or else to divert automobiles to steam or electricity.

Of course, if some of our modern bureaucrats had been in control, the problem would have been handled very simply, merely by slapping a price ceiling on gasoline and then rationing it as it inevitably became scarce! We might never have had a cracking process—and the United States would not today be a nation on wheels.

Not having to worry, however, about such arbitrary interference with the laws of supply and demand, Dr. Burton decided that the whole Whiting research staff should be put on the problem of cracking the relatively heavy fraction of petroleum known as gas oil. Although this research staff was probably the best and largest in the industry, it actually consisted only of Dr. Robert E. Humphreys and his assistant, Dr. F. M. Rogers, two other Johns Hopkins men. After two years of travail a successful cracking process was developed, and the first commercial Burton stills went into operation in the Whiting refinery in January, 1913. The process was a great success. During the next seven years the Company built hundreds of cracking stills and licensed some fifteen other oil companies to operate under the Burton and related patents.

RESULTS OF THE CRACKING DEVELOPMENT

The new process of cracking had many direct and indirect results. It doubled the yield of gasoline obtainable from crude and so assured the future of the gasoline automobile. It proved that the oil industry need not confine itself to separating and purifying what came from the ground, but could change the size and shape of the naturally occurring molecules. The comparatively high temperatures and pressures created many technological problems and stimulated research in the fields of metallurgy and refinery engineering. The by-products of cracking included large quantities of reactive olefinic gases, and these greatly stimulated research by chemical companies such as Carbide & Carbon and du Pont, who sought ways of using these interesting low-cost raw materials. Cracking brought many more technical men into the oil industry, and they soon penetrated every branch, stimulating research wherever they went. They even infiltrated into boards of directors! Today my own board of twelve includes ten "inside" directors, of whom three were trained as chemical engineers, two as chemists, two as mining engineers, and one as a mechanical engineer.

The policy adopted in regard to licensing of the cracking patents had an important effect on the course of technological development in the industry. The directors of the Standard Oil Company (Indiana) were faced with a difficult decision. It seemed fairly certain that the cracking process would make tens of millions of dollars a year for the Company as long as gas oil, the raw material, remained cheap and gasoline continued to be high priced. If the process were licensed widely, competition would rapidly reduce this differential and decrease the operating profits. On the other hand, it was also probable that competitive cracking processes could and would be developed.

The Company fortunately decided to adopt a liberal licensing policy, setting the royalties at a moderate proportion of the profits from the operation. The operating profits did decrease as anticipated, but the licensing policy established a pattern in our industry that has meant much to the rate of technical progress. In addition to royalties, the Company received return licenses from all their licensees on any improvements in cracking which the latter might make. In the long run these return licenses and the resulting operating freedom were probably more valuable than the royalty receipts, though these ran into the tens of millions.

The growing amount of royalties, whether received or paid, stimulated many companies to do research on cracking. In fact, once Dr. Burton had shown that cracking could be made commercial, the urge to do research on the process became almost universal.

Refining operations rapidly increased in complexity as well as size. As a result, the oil industry began to see the need for much greater use of chemical engineering. This trend began in the early 1920's, and it in turn emphasized the need for more detailed information about the thermodynamic behavior of hydrocarbons and mixtures of hydrocarbons.

All these factors combined to bring about the rapid growth of oil research and so eventually made the industry one of the most technically minded of all industries. The growth of the research department of my own company is perhaps typical. From 13 technical men in 1920, our parent company research staff grew to 70 by 1930 and to 140 by 1940. It numbers about 450 today, plus about 900 non-technical personnel; in addition, large research laboratories are maintained by several of our subsidiaries.

THE CATALYTIC REVOLUTION

The next great forward step was the catalytic revolution, and this, too, first became important in the field of cracking. For some twenty-five years oil cracking was brought about by heat and pressure under a wide variety of combinations. With the growing importance of catalysis in all sorts of chemical reactions, however, it was obvious to try to use catalysts to speed up cracking. Hundreds of catalysts were tried, but most of them were far too expensive for use in a field where an extra cost of a tenth of a cent per pound of product was considered high. Moreover, anything that speeded up cracking also speeded up coke formation, and in ten or fifteen minutes the coke deposit put the catalyst out of action. This seemed to most to constitute an insuperable obstacle. But Eugene Houdry, an independent French inventor, later assisted by the Sun Oil Company, kept plugging away until he developed a method of regenerating the catalyst by burning off the coke with air in fifteen-minute cycles. The superior octane number of the resulting gasoline made the process quite attractive.

The spirit of competiton led a number of companies to search for a process that would avoid the disadvantages of the Houdry process. The most novel and interesting solution was fluid catalytic cracking, one of the great contributions to chemical processing methods. In the fluid process the powdered catalyst is held in a turbulent bed through which the vapors pass. The powdered catalyst is continuously transferred by air or vapor lifts between the reaction and regeneration vessels at the rate of 1000 tons per hour and without a single moving part. Moreover, the heat resulting from burning off the 1 or 2 per cent of coke furnishes most of the heat for the whole operation.

OTHER CATALYTIC PROCESSES

As they became more familiar with catalysts, the research men of the oil industry found ways to use them for synthesis, isomerization, and other reactions as well as for cracking. Processes developed include hydroforming, polymerization, alkylation, and a number of catalytic desulfurization processes. Alkylation was fully as important as catalytic cracking in the 100-octane program of World War II and will be even more important in any future war involving piston-engine aircraft. Catalytic dehydrogenation produced the butadiene needed for the equally essential synthetic rubber.

CONDITIONS NEEDED FOR MOST PRODUCTIVE COMPETITIVE RESEARCH

While I have detailed only two out of hundreds of oil research achievements, I think it can be agreed that the industry and the nation owe much to oil research. We perhaps ought to review the conditions that have enabled it to operate so successfully and expand so rapidly. In the light of our experience, I believe that if competitive industrial research is to give the best overall results, a number of conditions are necessary. Among these are:

1. There must be a reasonable number of strong companies, able to attack problems aggressively from different viewpoints.

2. There must be a sound patent system to furnish incentives and at the same time to encourage prompt publication of research results. This permits cross-fertilization of ideas and also the combining of features from various sources to make the best available process.

3. There must be freedom and willingness to license others at

reasonable rates and to enter into cross-licensing arrangements where needed.

4. There must be no agreements in restraint of competition. A cross-licensing arrangement is in no sense a cartel. It does not set prices, establish quotas, or divide marketing areas. It fosters competition instead of discouraging it. Although a cross-licensing arrangement might be used as a means of enforcing a cartel type of operation, this has not been done by the American oil industry—to do so would violate both our competitive tradition and our antitrust laws.

COOPERATIVE RESEARCH IN PETROLEUM

The American petroleum industry believes in competitive research as the best method for most purposes. As this research has evolved, I believe it has avoided both the danger of too much duplication and the danger of too little variation in viewpoint.

Cooperative research has, however, been found necessary or desirable in several fields. One example is the fine work of the Coordinating Research Council, sponsored jointly by the automobile and petroleum industries. Their research projects on fitting fuels and lubricants to engines, and vice versa, have been carried out in various ways: by financing research at the National Bureau of Standards; through cooperative study of fuel performance in test fleets; and by assignment of various projects to the laboratories of individual companies. Projects have ranged from a determination of the desirable vapor pressure, octane number, and end point of motor gasoline in various engines to a fundamental study of combustion and the development of suitable tests for heavy-duty lubricating oils. This work has done much to promote better understanding between the industries and more rapid progress in making improvements available to the public.

RESEARCH SPONSORED BY THE AMERICAN PETROLEUM INSTITUTE

Another body of outstanding cooperative research has been that done under the sponsorship of the American Petroleum Institute. This research has had a rather interesting history. Shortly after World War I, Van H. Manning accepted the position of director of research of the newly formed American Petroleum Institute and endeavored to develop a broad program of industry-financed research in universities and other institutions.

Unfortunately, Dr. Manning's proposals did not distinguish between fundamental problems, well adapted to cooperative research, and practical problems, the solution of which would be expected to have immediate commercial and competitive value. Many of the strong individualists on the API board felt, with good reason, that all such research should be on a competitive rather than a cooperative basis, and the whole program was turned down.

Some of the industry leaders, however, saw the need for fundamental research, and about 1925 John D. Rockefeller, Jr., and the Universal Oil Products Company each offered to contribute $50,000 annually for five years to support basic petroleum research, provided the Institute would furnish the technical guidance. The API board accepted these offers.

Petroleum at the time was one of the most important, but least understood, raw materials in the world. Hundreds of different products were made from it, but little was known about its composition or its method of formation and accumulation.

During the first five years a total of forty-one different fundamental research projects were financed at about twenty-five different institutions throughout the United States. For the first time we began to understand the raw material with which we were working. Many of the participating universities were stimulated to do additional research in these interesting new fields.

The end of the five-year period covered by the first grants came at an unfortunate time, during the depression. However, the Institute agreed to continue the program on a somewhat reduced scale, raising funds on a voluntary basis from the company members. The budget has been steadily increased in recent years.

Results have been most satisfactory. The API research has repaid the industry—and so the public—many times what it cost. The present annual budget of well over $500,000 is, so far as I can ascertain, the largest amount being spent on fundamental research by any trade association, but it is still only half of one per cent of what the industry is spending on competitive research!

GOVERNMENT RESEARCH

In any discussion of research there arises question as to the proper place of government. This is a difficult problem. In some fields the government appears to be the best available agency. Examples are agriculture and atomic energy, fields where the overall public interest is large and where no private concerns exist that could or would carry out more than a small fraction of the needed research. Defense research must, of course, be largely financed by government. Again, the government is an appropriate agency for much of the research on standardization.

Even in some of the fields related to oil products, government research has seemed desirable. There is now sufficient petroleum in sight to last for several decades, and the industry is certain that much more will be found, but with demand growing so rapidly and new reserves becoming harder to find, attention should certainly be given to the possibilities of making synthetic liquid fuels from coal or oil shale. Pilot-plant studies in this field are quite expensive, costing more than most individual companies could reasonably be expected to undertake, especially since any resulting patents would probably expire before the processes would attain commercial importance. The industry has done considerable work in this field, but principally it has encouraged and cooperated with the U. S. Bureau of Mines.

The petroleum industry does not, however, share the view of those in the Bureau who assert, with some political support, that the government should shortly proceed to build or subsidize large-scale commercial plants at very high costs. Such plants would be obsolete before they were finished and would contribute less to the development of the processes than 5 per cent as much money spent on well-planned bench-scale and pilot-plant research and development.

Another phase of government research is the National Science Foundation, formed to encourage training and research in the basic sciences. The Science Foundation will be a fine thing if it does concentrate on this important and relatively neglected field, but if it should let its attention be diverted to the field of applied research, it would tend to inhibit rather than encourage such research, because private companies will generally be unwilling to enter a given field in competition with the government.

INDUSTRY ENCOURAGEMENT OF BASIC RESEARCH

As applied research expands, there is need for a corresponding expansion in basic research, which gives the new facts and theories with which to work. However, there has been a net shrinkage in basic research because of the drying up of most of the large volume of such work done in Europe prior to World War II.

The oil industry is well aware of this need for additional basic research and is taking steps to encourage it. The most direct step is the carrying out of more basic research in the companies' own laboratories. Such work is increasing, but is still not large in percentage. Many companies are also encouraging fundamental university research through the granting of substantial fellowships for graduate work. Most of these grants are made on the basis that the company does not influence the selection of recipients and acquires no rights to the results of the research work done by the fellows.

You are familiar with the rather large-scale research projects set up by certain universities and supported in part by industry. Examples are the nuclear research institutes of the University of Chicago and similar undertakings at the Massachusetts Institute of Technology and California Institute of Technology. Contributions by industry to these projects are now running well over two million dollars a year. Of the funds received from industry by the universities mentioned, about 30 per cent comes from the petroleum industry.

SOME THREATS TO RESEARCH

Enough has been said to demonstrate that we have a fair balance of different kinds of research in the oil industry. We believe that our research has evolved into a satisfactory and productive pattern.

In view of its outstanding past success, one might assume that oil research has clear sailing ahead. Actually, it faces a number of threats, as does all industrial research. Some people object to the whole idea of granting a temporary monopoly through patents and would emasculate our patent system. Others object to the competitive advantage which research gives. They wish to destroy any such advantage by compulsory licensing or by having the government do most of the research, thus removing the incentives for competitive applied research.

A few people even today fail to understand that technological unemployment is a myth so far as the overall economy is concerned. Whenever there is unemployment, they wish to declare a moratorium on research. It is noteworthy that such demands quickly subside in times of national danger.

High taxes are another deterrent to research; they not only reduce the funds available, but also reduce the incentive to develop and install new processes, when the possible profits would largely go to pay excess profits taxes. Still another threat is the drafting of technical men for non-technical military service.

NEED FOR ENCOURAGEMENT OF RESEARCH

As we view the world, both ancient and modern, we see comparatively few areas in which scientific research has existed on any extensive scale. Evidently it is a plant that needs a favorable climate.

Applied research on a major scale is really a product of the past third of a century. It has revolutionized many industries and raised the standard of living more than any other development in world history. We can hardly believe that its continuance would be jeopardized by its millions of beneficiaries. But just when research is becoming more difficult and expensive, we are faced with the widespread weakening of incentives and new threats to individual and business freedom. Research is today in real jeopardy unless you and I, who understand it, get its great story across to the public.

Let us not by our silence, or our preoccupation with scientific and industrial matters, permit the demagogues to bring about the killing of the goose that lays the golden eggs. Given a fair chance, research can contribute far more than it already has to enrich and lengthen human life.

If industry and science continue to do their part in selling as well as in achievement, I cannot believe that the people of the United States will deprive applied research, and the industries that sponsor it, of the freedom and the continued opportunity to which their record of past achievement so clearly entitles them. Despite the clouds on the horizon, I believe we can reasonably anticipate even more rapidly increasing benefits from industrial science than we have yet seen.

The Steel Industry

HILAND G. BATCHELLER

Chairman of the Board, Allegheny Ludlum Steel Corporation,
Pittsburgh, Pennsylvania

SPEAKING before the American Branch of the Newcomen Society in 1948, the illustrious Sir Louis Beale saluted American industrial power with all the insight and economy of words so typical of the educated Englishman. He said:

> The Iron Age is no figure of speech. In war and peace, our civilization rests upon *steel.* We know this fact so well that we usually overlook another: namely, that this *Age of Iron,* this Civilization of Steel, is primarily a spiritual creation.

Sir Louis emphasized again and again America's supremacy in steel. He also made the particular point that if we had preferred swords to ploughshares, we might easily have conquered our hemisphere, or even the world. But, in so doing, we would *not* have produced the world's highest standard of living. Or—at the opposite extreme—if we had valued material well-being so highly as to be incapable of military effort in two world wars against tyranny, then we might have avoided sacrifice for a while; but that course certainly would have lost us our self-respect and, ultimately, our liberty.

Sir Louis then pinpointed, back in early 1948, what we are all so conscious of today. He said:

> Because you have proved yourselves to be the spiritual masters of the Iron Age, you now face the challenge of world-leadership. This is the last and greatest, but also the most onerous, portion of your heritage from Great Britain.

> If you accept the challenge, you will shoulder a burden which is seldom lightened by gratitude or praise. If you do not, there is peril of annihilation for us all. Our common fate depends upon the use you make of our common heritage of steel—and the power it gives over the destiny of all mankind.

Certainly we are experiencing in one great rush all the heartaches, the costs, and the ingratitudes of world leadership. With all our industrial might, our high and ever mounting standard of living for all our citizens, I think we Americans can be justifiably proud of our role in organizing great portions of the world under the banner of individual liberty and dignity against the dark tyranny of Soviet deceit and degradation. Our youth and our wealth have been committed in Korea, and the barricades are gradually rising in both the Far East and the Middle East.

EARLY HISTORY OF IRON AND STEEL

If human effort is to be judged merely by its attainment, then the Sumerians, some 6000 years ago, with due allowance for date and circumstances, merit a preeminent place in lighting up a world elsewhere wallowing in primitive barbarism. We are the inheritors of highly developed Sumerian skills in astronomy, architecture, and law. In mathematics they could work with very large numbers. They were very proficient metal workers. Their gold and silver artifacts could be displaced today without embarrassment by our jewelers on Fifth Avenue.

Those ancients could make iron and steel. They also knew what it was to have a "shortage of steel." There is a fragment in old Assyrian cuneiform which states:

> As to the iron about which thou has written me, there is no good iron in my storehouse at Kizwatna. It is a bad time to make iron but I have ordered them to do it. When they finish I shall send it to thee. In the meantime, I send thee an iron dagger blade as a gift.

Later texts tell of converting iron into steel. Herodotus speaks of the Chalybians as a people of ironworkers, and Aristotle describes the production of steel by a crucible and carburizing process quite similar to that which is used even today.

This very early history is intriguing, but time does not permit us to explore it farther. As the late General Harbord said before the Newcomen Society in England:

> The roads you travel so briskly lead out of dim antiquity, and you study the past chiefly because of its bearing on the living present and its promise for the future.

The many centuries during which the great gulf of darkness descended on the world after the fall of the Greek and Roman Empires merit only passing reference. During this period the art of steelmaking was apparently lost.

As late as 1557 Christopher Encelius, one of the first metallurgists, probably thought that he had pronounced the last word of progress in metallurgy when he wrote as follows:

> First the substance of quicksilver and sulphur, mingled in certain proportions in the bowels of the Earth, become properly thickened with rooted moisture, finally produces perfect metal, first gold and then silver. On the other hand, the impure mixture of these two, not properly thickened or prepared, becomes either tin, lead, copper or iron.

Perhaps those who come after us, in the following centuries, will find our present-day knowledge almost as meager. Who knows?

Not until about 1600 was steel produced in England, as it was in ancient Ur. The process was that of packing iron with charcoal and heating to a red heat for a prolonged period. In these United States the production of steel by a similar cementation process was not begun until about 1730.

Prior to that year the activities in the New World were confined mostly to a scattering of crude ironmaking enterprises. The first effort was in 1619. A British company, appropriately known as the Southampton Adventurers, was organized to build a furnace at Falling Creek, near Richmond. The Indians of that area were direct actionists. Before the furnace could make iron the workers were massacred and the plant was destroyed. It was never rebuilt.

IRONMAKING IN COLONIAL TIMES

About 1645 there was built at what is now Saugus, Massachusetts, the first successful iron works in the New World. Ore was scooped from the adjacent bogs. Trees were felled and charcoal was made in the near-by forests. The solids were carried in baskets and dumped into the top of the stone furnace. The air blast was provided by a large bellows driven by a water wheel. The iron was cast into "sows," some of which were then remelted in forge hearths and worked up in a series of hammering and reheating operations into wrought iron. Some of the iron was cast into crude kettles and other utensils needed by the pioneers. A writer of that period described the workings of a similar furnace:

> They have been blowing at the ironworks, and have run from the last sixth day to this second day five sows of iron, which are commended for very good . . . and begin tomorrow to make pots.

The Saugus furnace is now being restored as a historic shrine by the First Iron Works Association.

SOME MAJOR DISCOVERIES

The development of the steel industry from Colonial to present times has been founded on a whole series of small steps forward in technology, based in part on the labors of practical men working by rule of thumb, and in part on the technological courage of imaginative men both here and abroad. Interspersed in this parade of modest improvements, piled one on another, are a few conspicuous discoveries serving to alter the science of steelmaking in a dramatic manner.

In 1852 Thomas, at Catasauqua, Pennsylvania, built the first really efficient and powerful blowing engine for blast furnaces in America; in 1856 Knab built the world's first by-product coke oven plant at Commentry, France—the early blast furnaces all had open tops with no provision for recovering the blast furnace gas made, but a closed top furnace was in operatioe near Mineville, New York, in 1868; a year later Cowper, in England, made a great stride forward by applying the regenerative principle to blast furnace stoves, whereby efficiency was greatly increased by utilizing waste heat of the furnace to preheat the incoming air for combustion.

The one great change standing out preeminently in this whole period is the development of the Bessemer converter for steelmaking. This rapid and inexpensive method of converting iron into steel of controlled analysis had overriding economic importance in the growth of the United States. It made possible the tremendous expansion of our railroads; this steel built our ships and the early multistory buildings. Without Bessemer steel the settlement of the West would have been long delayed. Henry Bessemer first described his "pneumatic" process for making steel in a momentous paper read before the British Association for the Advancement of Science in 1856. During that same year, Mushet made the Bessemer process practical by adding spiegeleisen to the charge after the blow to introduce manganese and carbon and to remove oxygen. In this country, Kelly claimed priority for the "pneumatic" process from 1846.

Without reopening the controversy as to who invented the "pneumatic" process, it is clear that its practical adaptation to the art of steelmaking resulted from the combined efforts of Bessemer, Kelly, and Mushet. Furthermore, it appears to have stemmed from the trained observation by Kelly in 1846 or 1847, as stated in his own words:

> To the processes of manufacture I gave my first and most serious attention, and, after close observation and study, I conceived the idea that, after the metal was melted, the use of fire would be unnecessary—that the heat generated by the union of oxygen of the air with the carbon of the metal would be sufficient to accomplish the refining and decarbonization of the iron.

Imagine the courage of Kelly's conviction that cold air could be blown through molten iron without chilling the iron. Rather the iron would boil and seethe with greater heat. It seemed so crazy that Kelly's father-in-law engaged a physician to examine him in order that he might be committed to an asylum. Fortunately the physician was convinced by his patient and, in turn, became an enthusiast for the idea. In 1864 steel was first made in the United States by the new process. History gives no indication of the subsequent relations between Kelly and his wife's father.

In the meantime, the Siemens brothers were developing a regenerative gas furnace which was finally perfected and applied to steelmaking with the cooperation of the Martin brothers. In 1868 the first open hearth steel was made in this country.

This new furnace made it possible to utilize scrap, which the Bessemer could not—furthermore, the open hearth permitted a more controllable reaction and the production of steels of higher quality. In later years the steel industry has turned more and more toward the open hearth, and recently to the electric furnace. Even today, however, the Bessemer survives for limited use.

All metallurgists owe a great debt to Sorby, who founded the science of metallurgy in England in 1863. In this country the Cambria Iron Company had the distinction of engaging the first American iron works chemist—in 1860. This marked the transition from alchemy and assaying to the beginning of metallurgy and chemistry as control tools in the production of steel.

In 1878 Thomas in England announced a method for removing phosphorus from steel by blowing it in a converter having a basic rather than an acid lining. Today most steel in the United States is made in furnaces with basic linings.

A multitude of improvements in steelmaking equipment followed in rapid succession. The first Koppers chemical recovery coke ovens constructed in this country began production in 1908, using the cross-regenerative principle to achieve higher thermal efficiency and great operating economy.

In 1913 the Englishman, Brearly, and the German, Strauss, discovered new alloys, approaching the noble metals in their resistance to corrosion, and the stainless steel industry was thus born.

By the 1920's the blast furnaces had grown to huge size, the coal and iron ore were being scooped from the ground with awe-inspiring mechanical juggernauts. Meticulous technical control had become a handmaiden of steel manufacture.

The continuous rolling mill, the large electric furnaces and the flowering of alloy steel metallurgy all combined to make the 1920's and 1930's decades of production records and technical proficiency.

JOE MAGARAC PLAYS A PART

Through 1850 the change and growth had been based primarily on man's unaided senses, with heavy accent on the pick, shovel, and wheelbarrow of Joe Magarac. Steel men look respectfully back to the Biblical Tubal Cain, but in the taverns along the Monongahela the workers still talk of the exploits of Joe Magarac, the fabled Paul Bunyan of steel.

> Joe was the biggest, strongest, laughingest man that ever stepped out on a pouring platform. He had a back as broad as a door, a neck as thick as a bull's, and arms as big as a ladle plug. When his steel-blue eyes sparkled in his ever-present grin, you could see light flash from polished metal. And when he stripped you could see spring steel in every muscle of his seven-foot frame. Joe Magarac was a real steel man. He was the fellow who heaped up Minnesota's Mesabi iron ore range and squeezed out railroad rails with his bare hands; he made cannon balls the way you would snowballs, and he melted himself down into a ladle so that America would have the world's best steel mills.

After Joe melted himself down, along came the professors to teach us to reach beyond our reach. Even as far back as 1824, the oldest surviving school of science and engineering in the United States was established by the great Dutch patron, Stephen Van Rensselaer, to teach the sons of farmers and mechanics the application of science to the common purposes of life. The many engineers from this and all other engineering schools that were subsequently established fanned out all over the country to fashion out of Joe Magarac's relatively crude industry the almost unbelievable complex which is our steel industry today. This swelling stream of young trained engineers combined the eternal bounce of youth with the scientific knowledge of why things happened as they did. They leavened the loaf of practical experience and dared new methods to modify the rule of thumb. It was these men, of untold number, who shifted the burden of physical labor from Joe Magarac's shoulders to the machine; who released the industry from the maze of trial and error.

And now this amazing industry is again involved in unprecedented growth and seething with technical innovations on an enormous scale so typical of American ingenuity.

PRODUCTION GROWTH

In 1810 the United States produced a mere 1000 tons of steel, and in 1850 about 6000 tons. After the introduction of the Bessemer and open hearth processes, these yearly quantities climbed rapidly from 13,000 tons in 1860 to 11,000,000 tons in 1900. At the beginning of 1951 the industry's capacity stood at 104,000,000 ingot tons. And even more is on the way to meet a growing civilian economy and an ever ominous military challenge.

In 1952 nearly 1,000,000 tons of new capacity will come in each month, and in 1953 the total will exceed 120,000,000 tons. Think of it. In that year alone we will have the facilities to turn out as much steel as all the steel made in this country during the entire period from Colonial days on through the year 1905.

The machines for producing this stupendous tonnage almost defy description. Blast furnaces with daily capacities up to 1800 tons; open hearths which melt and pour as much as 500 tons in one heat. Electric furnaces whose monster tops swing back to swallow 75 tons or more of raw materials in one gulp. A battery of four such furnaces, recently installed, having a metal area and volume not much larger than that of two ordinary office rooms, will have a total electric input of 64,000 kva or 75,000 electric horsepower, which in itself would be enough to take care of a good-size industrial town for all its lighting, heating, and industrial applications; modern blooming mills, with an electric drive as large as 12,000 horsepower on the main rolls, will reverse from 70 rpm in one direction to 70 rpm in the other direction in approximately one second; continuous hot mills rolling wide sheets at 30 miles per hour and tandem cold mills at a top speed of 80 miles per hour; 25-cubic-yard buckets up in the ore fields chewing out 1700 cubic yards of ore each hour; great coal "laundries" which grind, wash, and classify the inferior coals into metallurgical grades; oxyacetylene flame jets piercing blasting holes in the ore deposits; aircraft dragging magnetometers through the sky to uncover new ore deposits; great ore boats threading down through the Great Lakes on the all-weather beams of radar and loran. All these are but a few of the physical manifestations of the equipment which has been devised and the human energies that are expended to sustain yearly production of 120 million tons of steel.

NEW CHALLENGES FOR THE METALLURGIST

This great complex is the culmination of knowledge encompassing all the sciences. They all have contributed to the metallurgical art of extracting metals from their ores and adapting them to man's use *in the most economical way*. The entire development has been one primarily of increased and cheaper steel production. So far, the pressure on the metallurgist has not been more than he could carry. After all, the Sumerian metalworker was ahead of related sciences both in knowledge and useful theory. The Renaissance metalworker was abreast of the demands on his industry. The Colonial steelmaker was quite able to meet the simple demands of a frontier economy. Until recently the metals and alloys originating back to primitive times were sufficient for all needs. Printing, the steam engine, the electric generator and the engines of war all found acceptable metals readily at hand, and even the airplane grew apace with the skill of the design engineer and never was limited by the lack of metallurgical advances.

In recent years the metallurgist has been faced with a host of new challenges. Engineering design is now frequently limited by the metals at hand; metals and alloys frequently have become the critical limitation determining the complete realization of engineering design.

As Cyril Smith, Director of the Institute for the Study of Metals, has said:

> The design of gas turbines, rockets and nuclear power are all crucially dependent on the development of better materials. Throughout most of history, the important figures in metallurgy have been those who, through improved chemical processes or handling methods, have cheapened and expanded production. In the future the important figures will be those who permit the development of better and better properties.

Couple this viewpoint with that of Dr. Harold Moulton of the Brookings Institution, who postulates a population of 300 millions in 2050 A.D., having living standards eight times as high as at present.

With such challenges and the natural and applied sciences progressing so much more rapidly than economics and the humanities our younger scientists will within the next few years be participating in the developments not yet conceived.

What may we expect? We can no longer depend entirely on the usual process of mixing the elements into new compositions and putting them through variations of conventional heat treatments in order to improve their properties.

Let us make the metals twice as strong as at present, five times as strong, ten times as strong. Physicists are already aware that the forces holding metal atoms together in the crystal are such that strengths at least ten times those achieved are within the realm of possibility.

Dr. Smith has indicated that metal crystal lattice vacancies, dislocations, mosaic blocks, microcracks, or similar types of disorder in the metal crystal are responsible for the weakness in metals. So the physicist may pick up the challenge which the metallurgist picked up from Joe Magarac. The physicist, or more probably the physicist and metallurgist together, can be expected to evolve an explanation of why slip and fracture occur at low stresses and then can go on to devise a means to interfere with this mechanism.

One may also expect the physicist to trace down the reason for superelectric conductivity, a phenomenon which many metals show at low temperatures and for which there is yet no satisfactory explanation. They will eventually increase the temperature at which this superconductivity persists, with stupendous economic and design ramifications for the electrical engineer.

One may expect an increasingly rapid use of radioactive isotopes as tracers in research and process control. Tracers will be used for studies of self-diffusion and of many types of reactions as, for example, slag metal reactions, absorption, and corrosion.

As another by-product of nuclear physics, much will be learned about the nature of metals by observing the effect of radiation on their structure and properties. Atoms can be knocked out of their lattice sites by powerful neutrons, and two atoms can be made to replace one when fission occurs. The development of nuclear energy has put the spotlight on uranium, plutonium, beryllium, zirconium, and titanium. The new jet engines and supersonic aircraft have accelerated the development of molybdenum, vanadium, and complex alloys of iron, nickel, cobalt, chromium, and columbium in the search for metals to operate at high stress for long periods at red heats.

These relatively rare metals are all developing into industries of their own, with titanium the most dramatic in its possibilities because of its unprecedented strength-weight ratio. Several years ago titanium was available to only a few research workers in ounce lots, whereas in 1952 the production of this metal will most likely exceed the 5000-ton mark.

I think we may also expect almost unbelievable application of ultrasonic energy and the use of electron beams in steel production, metallurgy, and the fabrication of metals. Already they are using these energies for drilling and machining metals at speeds and with accuracies almost beyond human belief. Ultrasonics may well exert a profound influence in extractive metallurgy—for the separation of larger and larger quantities of metals from the ever lower grades of ores that of necessity must be exploited. And the effect of ultrasonics on crystal growth or crystal alignment in metals is an entire new science so far just barely scratched.

THRESHOLD OF A NEW TECHNOLOGY

The next several years may witness the development of another great step forward in steelmaking. For centuries metallurgists have had the persistent dream of continuously pouring molten metal into a water-cooled mold from which it will constantly emerge as a solidified, cast section of appropriate shape, to be automatically cut to lengths suitable for further processing.

The dream now appears to be well on the way to realization. Such a process has been perfected for nonferrous metals and is well along through the pilot-plant stage in steelmaking.

Or consider those newly developed alloys for specialized and high-temperature service which are so extremely tough that they cannot be machined and thus must be cast to precise shape. This is done by utilizing the "lost wax" process of the ancients, a method of building up a shape with wax, using this shape as a pattern, then melting out the wax and pouring in the molten alloy. Now industry is making the patterns of plastic, as well as wax. Several groups are developing the use of frozen mercury as a pattern material. Imagine a foundry with deep freezers scattered around holding mercury pattern at −80°. It is enough to make an old-time foundryman goggle in disbelief.

So it is with progress in the steel industry. Great as the industry will stand with its 120 million tons of annual capacity, awe inspiring and ingenious as is its productive equipment, we are merely on the threshold of a greater technology. Building soundly on the heritage of the past, freedom of the individual American and the active competition of a democratic society, applied science has brought us this far and will carry us into the future. Let us hope that this future is a more fruitful life and a higher standard of living not only for our children and grandchildren but also for all the other children scattered throughout the world. Let us hope that all this energy does not have to be diverted to defend our way of life against the Communist philosophy of freedom which Engels defined as follows:

> If I drop a stone from my hand, that stone is free because it must obey the law of gravitation. So you are free to the extent that you obey the law of the dictator.

All the progress in steel- and metalworking of tomorrow, today, and the yesterdays, stretching all the ages back to our origin, has real meaning only as it makes life fuller and easier for everyone, where there is no transgression on human dignity and individual freedom. The healthy, inquiring minds of our young metallurgists, physicists, and chemists working in true partnership with the progeny of Joe Magarac have a lot of surprises in store for us. As the Philadelphia journalist, J. A. Livingston, puts it in his parody of Lewis Carroll:

Gather round, gather round, the Professor is coming,
He's coming here to teach;
He'll teach us how to do such things
As reaching beyond our reach.

The Communications Industry

J. B. FISK

Director of Research, Physical Sciences, Bell Telephone Laboratories, Murray Hill, New Jersey

COMMUNICATION here means simultaneous, two-way, electrical communication, particularly telephone communication. It is to be differentiated in several ways from other industries in which science plays a prominent part.

SOME CHARACTERISTICS OF THE TELEPHONE INDUSTRY

The telephone industry is primarily a *service* industry. This service consists in transmitting intelligence from any one of about 40 million points in the country to any other of the 40 million—and to many other countries. New materials and new products are exploited not for themselves but as they find application in communication technology.

A second characteristic which differentiates the telephone industry from most others is its *systems* aspect. The telephone industry is a nationally integrated system of wires, cables, radio links—switching and control mechanisms—a great variety and number of complex instruments which together reliably reproduce a word spoken here, instantly, undistorted and undiminished thousands of miles away.

The scope and complexity of the modern communications job leads naturally to a great breadth of scientific interest and to a reliance on science, both of which we will discuss in some detail.

Part of the story of science in electrical communication is known to everyone. The electric principles were laid down in large part by Faraday and Maxwell; by Kelvin and Rayleigh. The inventions of Bell in telephony, Marconi in radio, and de Forest in electronics followed. These principles and these inventions can safely be said to be the foundations of tele-communications. But this just begins the story; it gives almost no clew to the present position or scope of science in the tele-communications industry.

To give some indication of this scope we will take examples from organic chemistry, metallurgy, mathematics, and the physics of solids. Examples could come equally well from many other areas, e.g., physical chemistry, acoustics, electrochemistry, mechanics, or electron physics. Space will not permit the mention of other areas where scientists and engineers are finding new uses for new principles and new materials.

The communications industry has a vital interest in many materials and some interest in almost all materials and, while we are not primarily manufacturers of materials, we must be intelligent consumers. To be intelligent consumers we must know what materials are available and what their properties are. We must know why materials have the properties they do so they may be properly used and their properties specified and controlled. And we must know chemical, metallurgical, and physical principles for making new materials to meet our special needs. This implies a high degree of competence over broad fields, which we try to maintain.

Polymer Chemistry

In the telephone industry there is widespread use of plastics of many kinds: in telephone handsets, in capacitors; as electrical insulation; as cable covering. The fundamental studies of molecular structure by our physical and organic chemists give us assurance in these applications. These chemists contribute to the science from which they draw and have been in turn helpful to the plastics industry itself.

Metallurgy and Crystal Growth

The use of metals in the communications industry is widespread: copper, steel, lead, aluminum, and many other metals and alloys. We go to the suppliers for most of these, but at times the needed material does not exist. We turn then to our metallurgists and physicists, for example for a magnetic alloy of some particular property or to find a substitute for some strategic material. At the moment, for basic studies in semiconductors, we want germanium or silicon of purity, one part in 100,000,000 or better, and we want the bulk material in the form of a single crystal. These aims we now achieve and these materials will play an important part in the future of communications, as we shall see in a moment.

Mathematics and Information Theory

Now, in mathematics, the applied mathematician is usually thought of as the person to whom a particularly nasty equation is brought for solution and who solves it. But over the years, mathematicians have found a still more important role to play in the communications industry. This is partly a matter of time and maturity and partly the nature of the business. A great deal of communications technology is based on abstractions of the mathematician and scientist. For example, the basis for carrier telephony is an abstraction which has led to single side band transmission, and simultaneous messages on a single pair of wires. So also is the concept of impedance, known to every electrical engineer. The concept of modes in waveguides, first discussed by Lord Rayleigh, finds a practical application in TD_2, the transcontinental microwave radio relay. Now comes information theory: the mathematicians, having led us through the maze of amplifying tiny signals 10^{1000} times without distortion, are now turning attention to the question, "Was all the message worth sending?" What was its true "information content" and are there ways to "code" a message to make transmission neater?

Physics of Solids and the Transistor

In physics, the most absorbing current example comes out of basic studies, commenced a few years ago, of the conduction processes in semiconductors like germanium. These studies led to the transistor.

Transistors are a remarkable new type of circuit element which perform functions analogous to those of vacuum tubes but, unlike vacuum tubes, require no vacuum and no hot filament. Thus they are free of two major causes of vacuum tube failures. They also are much smaller than vacuum tubes and consume less power. They perform efficiently as amplifiers and as oscillators and in many other types of circuits where vacuum tubes have traditionally been used. Although they perform functions similar to vacuum tubes, they are not identical in their characteristics and, in order to use them effectively, a new art of circuit design is required. They have their own peculiar limitations, but for some applications their performance is superior to tubes.

The invention of the transistor was a direct outgrowth of research to understand the properties of semiconductors. This understanding is now so comprehensive that design principles have been laid out and the operation of units predicted accurately, well in advance of construction and trial. This circumstance, unusual in so new a field, means that design objectives are usually clear—what to do is understood; how to do it is the problem, and attention can be focused.

The earliest transistors were made in 1948. They consisted of small pieces of the element germanium with the points of two hair-like wires touching one side of it, very near to one another, and with a flat metal connection on the other side. More recently, another form has been developed which does not depend on fine point contacts for its operation. Instead, it is a very carefully grown single crystal of almost, but not quite, pure germanium. The very minute amounts of impurities are of two different kinds intentionally inserted in stratified layers. Valuable properties of the transistor are due to this arrangement of impurities. Single crystal transistors, particularly single crystal "p-n junction" transistors, are the bases for present research and development. They are the units which have given the recent, very important results.

Transistors may replace vacuum tubes in many applications. However, their principal uses may very well be in fields where electronic control or amplification have been excluded in the past for reasons of economy, space, and power.

Communications technology is more complex as time goes on. Each new subscriber must be provided with the means to communicate quickly and effectively with every other subscriber. The complexity is basic. Low cost and great reliability are dominant. With an understanding of the real content of messages and then sending only what is significant, with new techniques and new principles, with new materials and new devices such as transistors, a foundation is being laid for the communications systems and facilities of the future.

Meanwhile the communications industry recognizes its debt to all science and attempts to repay, at least in part, by contributing in kind.

The Chemical Industry

NORMAN A. SHEPARD

Chemical Director, American Cyanamid Company, New York
City, New York

FROM the date in 1828 when Friedrich Wöhler converted ammonium cyanate into urea and demonstrated that a material produced in the metabolism of the human body could be man-made in the laboratory until the serendipitous discovery of the first synthetic dyestuff by William Henry Perkin in 1856, there was little or no organic chemical industry in the world or activity of a chemical nature that could be dignified by the name of industry.

The synthesis of urea exploded the theory that such materials required some unknown influence called "the vital force" connected with life itself. The discovery of a dye, when attempting a synthesis of quinine from aniline, focused attention on the practicability of organic chemistry to meet the needs of man, and, slowly at first, but then with ever rapidly increasing tempo, an organic chemical industry came into being. Prior to those days there had been an inorganic chemical industry. The liberation of metals from their ores dates back to prehistoric times, as does glassmaking. And in the organic field many organic materials were used, such as natural dyestuffs and sugar. Organic products involving chemical reaction, however, were relatively few. There was soap from fats and wood ashes, spirituous liquors and vinegar by fermentation of fruit juices, to give a few examples. The production of these materials were arts, and how they came into being is only a matter of conjecture. Why the phenomena occurred and what the underlying reactions and chemistry were, was a mystery.

We have come a long way since those days. It would be impossible within the limits of this paper to trace the advances step by step which led to the status of today. I can only attempt sketchily to cover so broad a topic as the industrial status of the various types of primary chemicals and the numerous end product chemicals that are available today.

ACIDS

Sulfuric Acid

Let us look first at the most important of all acids, sulfuric acid. It was a great discovery when the lead chamber process was developed, utilizing pyrites as the source of sulfur dioxide and nitric acid from saltpeter as the oxidizing medium. Today the clumsy, dirty, space-consuming lead chambers have disappeared (though I can well remember them in my college days), superseded by the clean, sleek, efficient catalytic equipment of today.

It is interesting to mention that while pyrites continued for some years as the source of sulfur, it had during the past twenty years been almost completely replaced by elemental sulfur, sprayed in molten form into the sulfur dioxide furnaces. Today, owing to the tremendous demands for sulfuric acid and the severe shortage of sulfur, millions of dollars are being spent to convert these installations back to pyrites burners. As a result, pyrites mining is experiencing a real revival, as is also the beneficiation of its low-grade ores.

Of very recent introduction is a quite radical modification of the catalytic process, radical both in equipment and in operating procedure. This modified process, emanating from extensive research in my own company, permits economical operation of smaller units of lower investment cost and at a conversion efficiency higher than is obtainable in standard contact plants.

Nitric Acid

Relatively little nitric acid is today manufactured from saltpeter. Again a catalytic process superseded the old one. Ammonia is oxidized over a platinum gauze much more economically. As early as 1935, more than 90 per cent of the nitric acid produced came from ammonia.

Hydrochloric Acid

Formerly made exclusively from common salt and sulfuric acid, an appreciable percentage of the total hydrochloric acid is now made by the direct combination of chlorine and hydrogen, or is obtained as a by-product from the chlorination of hydrocarbons.

ALKALIS

Caustic Soda

The process for caustic soda has not changed much recently. The development of the electrolytic process from sodium chloride brine to chlorine and sodium hydroxide has largely superseded the old LeBlanc process. This happened many years ago, stimulated by the tremendous increase in the demand for chlorine for intermediates, chlorinated hydrocarbons, resins, etc. Relatively little caustic soda is made today by the causticization of soda ash with lime, though the process is cheaper. The demand for chlorine is so great that at times the caustic produced simultaneously has been greatly in excess of the demand.

Ammonia

Originally procured from the coke ovens and later by the fixation of nitrogen by the cyanamid process, followed by acid hydrolysis, ammonia today is almost exclusively made directly from nitrogen and hydrogen by the Haber catalytic process. The multiplication of these huge units continues, in spite of the tremendous already existing capacities, stimulated by universal demands for nitrogen for fertilizers and for explosives, in these days of mobilization to avert a worldwide conflict.

METALS

While it is hardly within the sphere of this review to cover metals, I would be remiss in not mentioning magnesium and one of its sources, magnesium chloride from sea water. This development, linked with the recovery of bromine from the same source, clearly demonstrates the resourcefulness of the American chemical industry in meeting a demand for a magnesium salt for the electrolytic process for the manufacture of magnesium metal and for bromine to meet the demands for ethylene bromide in ethyl gasoline.

This mention of magnesium leads me to speak of the very recent production of metallic titanium. The manufacture of this metal from titanium chloride surely comes within the scope of "The Chemical Industry Today." Titanium metal and its alloys are of great importance because of their weight-strength ratio, stability at high temperatures, and resistance to corrosion.

DYESTUFFS

The Germans were not slow to recognize the significance of Perkin's discovery of mauve. They built up a dyestuff industry which, by the beginning of World War I, produced dyes that practically replaced all the natural or vegetable dyestuffs, such as indigo, Tyrian purple, madder, and cochineal, and which had captured the world market for dyestuffs. We were almost entirely dependent on German sources and remained content to be so until cut off from this supply by the war. Our predicament was so serious that no time was lost in rectifying the situation, and today America occupies the position formerly held by Germany as leader in this industry.

Practically every dyestuff requirement has been met, both as regards brilliance and stability on the natural fibers, and also for the rapidly expanding list of synthetic fibers. Recent additions are the fluorescent dyes, so striking in their application to signboard advertising and so prized by children in caps, ties, and other articles. Also of very recent origin are the brighteners that make white so much whiter and pastel shades so much clearer and that are finding increasing application in detergents for washing fabrics.

OTHER ORGANIC CHEMICAL DEVELOPMENTS

In the development of the dyestuff industry many intermediates were required and many by-products were obtained that led to extremely important developments in other fields and, as knowledge of organic reactions grew, led to the establishment of other industries. Some of these are greater in size and importance than the dyestuff industry: the branches of the chemical industry making synthetic resins, synthetic rubber and rubber chemicals, synthetic fibers and textile chemicals, chemotherapeutic agents, insecticides, fungicides and fumigants, petroleum additives, and food additives, including preservatives, flavoring materials, and surface-active agents.

Alcohols

Not long after the discovery of the Haber process for ammonia, the process was applied to the synthesis of methanol from carbon monoxide and hydrogen. This was stimulated by the increased demands for formaldehyde, readily obtainable by the catalytic dehydrogenation of the alcohol over platinum. Haber process equipment is quite easily converted to the manufacture of methanol. The preparation of aldehydes and ketones by the direct oxidation of aliphatic hydrocarbons is now practiced on a large scale, especially for the production of formaldehyde and acetaldehyde.

Terminally unsaturated hydrocarbons from the cracking of petroleum provide starting materials for various alcohols. The process is a simple one of hydration. Ethylene gives ethyl alcohol. It is difficult at present to estimate what percentage of industrial ethanol is synthetic. To produce enough alcohol for conversion to butadiene for the synthetic rubber program, fermentation alcohol is being diverted from beverage usage, and synthetic alcohol capacity is being greatly expanded. It appears probable that after this emergency is over, synthetic alcohol will supply almost all the requirements for industrial ethanol.

Propylene is the main source of isopropyl alcohol, and some of its homologs are the source of higher alcohols. Reduction of long-chain acids, usually in the form of their esters, is an important method for the production of the long-chain alcohols. The Fischer-Tropsch process, which converts gaseous hydrocarbons into liquid fuels, has as by-products, alcohols, aldehydes, and acids. By modification of the process (Oxo-process and others) the amounts of these by-products may be varied. These processes are currently in the early stages of production, and when the manufacturing difficulties are overcome, promise to increase greatly the production of alcohols and organic acids.

The unsaturated hydrocarbons also furnish starting materials for the manufacture of the polyalcohols, the glycols. Ethylene is the source of ethylene glycol and ethylene oxide; propylene the source of propylene glycol and of synthetic glycerol. The former two are produced in huge quantities, ethylene glycol for antifreeze, for explosives, and for alkyd resins, the oxide as an intermediate in the manufacture of acrylonitrile and, among other things, various surface-active agents of great importance.

In connection with unsaturated hydrocarbons mention must be made of acetylene, for acetylene, either from calcium carbide or by the controlled oxidation of natural gas, is becoming more and more important in chemical synthesis. Its use in making chlorinated solvents is of long standing, as well as its hydration to acetaldehyde, and on to acetic acid, acetic anhydride, and acetone. So also its role in the neoprene synthetic rubber process. As a vinylating agent it has many applications. Vinylation of hydrochloric acid to produce vinyl chloride and of acetic acid to make vinyl acetate has long been practiced. Recently the reaction has been applied to hydrocyanic acid for the production of acrylonitrile and to many other classes of compounds, such as alcohols to form vinyl ethers.

Organic Acids

One of the earliest of the catalytic processes to be applied on a very large scale was that for the production of phthalic anhydride from naphthalene by oxidation over a vanadium catalyst. Maleic acid is a by-product and is also prepared by a similar process starting with benzol. This acid and the isomeric fumaric acid are important intermediates in alkyd resin manufacture.

Severe shortage of naphthalene and ever increasing markets for phthalic resins have turned phthalic anhydride manufacturers to *o*-xylene from the petroleum industry as a substitute for the naphthalene. A recent advance in the process is the utilization of fluid catalyst methods in place of the static catalyst bed. Here also should be mentioned the important synthesis of adipic acid from furfural. This conversion of corncobs into "silk" stockings via nylon is a triumph of chemurgy.

Of very recent origin is the production of hydrocyanic acid directly from ammonia and methane by a catalytic oxidative process. This process has been stimulated by the very large increase in requirements for this acid. Formerly used largely as a fumigant, it is now an important intermediate in the manufacture of resins, synthetic rubber, and synthetic fibers. This new catalytic process from ammonia and hydrocarbon gases holds promise of producing hydrocyanic acid at a lower cost than either ammonia and metallic sodium, through sodamide by fusion with carbon to sodium cyanide, or from calcium carbide and nitrogen to calcium cyanamid, fusion with salt to sodium cyanide, followed by liberation of the free acid from the sodium salt by means of sulfuric acid.

Synthetic Resins

Though Baekeland discovered and developed the phenolformaldehyde resins in the first decade of this century—the first of the almost innumerable truly synthetic resins to be commercialized—these resins were slow in taking hold. They were almost curiosities, substituting for amber in pipestems and beads and becoming the base for a few coatings. Their most important application was in electrical insulation, but their future for another decade was far from assured, and few realized that another extremely important branch of the synthetic organic chemical industry had been born.

Progress was made through the 1920's. The alkyd resins (polymerized polyalcohol polyacid esters) were introduced, as were also the urea-formaldehyde resins (late 1920's), but it was not until the 1930's that rapid progress in the application of synthetic plastics was made, with many new materials entering the field. Nitrocellulose plasticized with camphor as celluloid, introduced around 1870, had long since found considerable application as a film-forming material and in molded novelties. Cellulose acetate was replacing it in the photographic and moving picture industries. Nylon, the first of the completely synthetic fibers to be developed, was announced in the middle 1930's. Although ordinarily thought of only in connection with fibers, this polyamide has many important applications in the molded-resin field.

By the middle 1930's polyvinyl chloride, the vinyl esters, vinyl acetate, and the acetals, were attracting notice, and soon thereafter ethyl cellulose and polystyrene, as well as the vinyl chloride-vinylidene chloride copolymers. The polyacrylates, those clear, transparent products functioning as bomber noses and windows in airplanes where glass failed to meet the requirements of low gravity and low shatterability, filled a vital need during World War II.

It was at the end of the 1930's that the melamine-formaldehyde heat-setting resins were introduced. These have broader applicability than the ureas owing to their superior water resistance and stability. Rapid expansion of melamine capacity has been necessary to keep up with the demand. All these classes of synthetic resins have moved up into the high volume class and have met various requirements: insulation, moldings of various types—housings for radios, scales, tableware, etc.—surface coatings for automobiles, for electrical appliances, and for military equipment, coated fabrics for rainwear and for hospital sheetings, adhesives and textile finishing agents for crease- and shrinkproofing, stabilization, softening, and fire retardance; treatment of paper to produce high strength when wet; of leather for finishing as well as in processing; sandwich glass; ion exchange resins, and many other uses.

Then followed in the 1940's the silicones, the fluorocarbons, the polyester resins, polyethylene, and various copolymers, such as those using acrylonitrile. And there is every indication that the end is not yet. The importance of these developments is hard to evaluate, especially in these mobilization days when most metals are in short supply and resin-fiber combinations of high structural strength can serve as satisfactory or even superior substitutes in many cases, besides filling many essential uses where metals are not suitable.

Synthetic Rubber

This story has been told so many times that I shall not dwell on it for long, though my inclination to do so is great, for it is a field with which I am particularly acquainted.

In the emergency produced in World War II by our being cut off from an adequate supply of natural rubber for our military and civilian economy, our chemists and chemical engineers accomplished what appeared to be the almost impossible in providing this country with an adequate supply of rubber and prevented a catastrophe. This general purpose rubber made by the copolymerization of butadiene and styrene, though inferior in some respects to natural rubber, together with the stockpiled natural rubber, met all our requirements for tires, both civilian and military. And the special purpose rubbers, neoprene from chloroprene, the acrylonitrile-butadiene copolymer, and butyl rubber from isobutylene and a small percentage of isoprene, supplied the needs for oil-resistant rubbers and, in the case of butyl rubber, inner tubes, better than those made of natural rubber.

Since World War II, through conducting the emulsion polymerization at lower temperatures and introducing a new type of furnace black for reinforcement, a synthetic rubber combination has been made that is superior in wear resistance to natural rubber and is especially suitable for tire treads. Promising experimental elastomers developed in the government rubber program or by industry are continually being subjected to service tests, but, to date, I have not heard of any that equal natural rubber for use in the carcasses of large tires, where the present synthetics fail because of their high hysteresis loss, causing the accumulation of heat in the interior of the tire and eventual failure.

Rubber Chemicals

With the discovery of Oenslager, in the first decade of this century, that aniline, thiocarbanilide, and certain other organic chemicals would accelerate the vulcanization of rubber, both the chemical and rubber industries applied much research talent to investigating possible additives to rubber to improve the quality of rubber goods, not only materials for speeding up vulcanization but also age resistors, plasticizers, reinforcing agents, and organic coloring agents. Cheap and efficient accelerators, antioxidants that increased the life of vulcanized rubber many-fold, and reinforcing agents, notably carbon blacks, through their combined effects and with the fabric and design improvements, made 30,000- to 35,000-mile tires possible. Effective antioxidants had the disagreeable characteristic of discoloring white and light-colored rubber goods. Within the past two years one has been discovered that is completely free of this objection and yet affords protection equal to the best of the discoloring materials.

Synthetic Fibers

The advances in this field have, as in the case of synthetic rubber, been highly publicized. Viscose rayon, for many years produced largely for use in feminine attire, entered the industrial field in the early 1930's in the form of the high-tenacity yarns and has now largely replaced cotton for use in tire cords. This, with the increased public acceptance of the beautiful delustered fabrics, has led to tremendous expansion of manufacturing facilities.

Nylon, with its capture of the ladies stocking market and many other items formerly made of silk, continues to expand its markets, with greater and greater volume going into military items. The acrylic fibers, Orlon, Dynel, and Acrilan, recent additions to the list, are copolymers, in two of which acrylonitrile is the major monomer. These fibers, with their remarkable stability to insects, molds, and weather conditions, also have characteristics more nearly approaching wool than the previous man-made fibers. Fabrics of these fibers, as well as of Dacron, also known as Fiber V and Terylene (British), have remarkable resistance to wrinkling and the unique characteristic that a crease once set by heat persists, even after laundering. These factors make these acrylic fibers especially desirable for suitings and promise a rapidly growing market for them. In pile fabrics they produce an amazing match for moutin and are already being applied for use in military garments. The polyester Dacron, from terephthalic acid and glycols, appears to have special merit for use in suitings, shirtings, and neckties. These items wash beautifully, dry rapidly, and are quite immaculate without ironing.

A recent announcement (December 15, 1951) divulges that a transparent base for photographic film has been developed from a polyester chemically related to Dacron. This film is stated to be several times tougher than any of the present types and retains its original dimensions and properties over a wide range of atmospheric conditions. Producing the intermediates for these new fibers is taxing the ingenuity and production facilities of the chemical industry and leading to large new capital investment, especially as they, together with nylon, are of such military importance.

Although glass fibers are not considered to be of synthetic origin in the sense that the organic fibers are, they should be mentioned here. The fireproofness and remarkable insulation value, as well as reinforcement capacity when used in combination with certain polyesters, give them a unique position among fibers. The last property makes possible the production of high strength laminates in combinations suitable as a substitute for sheet metals that are in short supply. In addition to being noncorrosive, these glass fiber laminates have the advantage of lower weight. Military craft, even up to 35 feet in length, as well as many other military items, have been fabricated from these glass fiber-reinforced resins.

Insecticides

Many new products of great effectiveness have been developed during and since World War II. No longer is the farmer dependent only upon such chemicals as paris green, lead calcium, and magnesium arsenates, pyrethrum, and rotenone. He now has DDT, benzene hexachloride, Chlordane, allethrine and parathion, far more effective agents and, in general, toxic to a greater variety of insects. This is especially true of parathion.

Surface-Active Agents

These materials, so important as wetting agents, emulsifiers, dispersing agents, and detergents, have received and are receiving much attention from the chemical industry. For thousands of years soap was practically the only material available for these purposes. Today there are tailor-made products to meet almost any requirement. Soap's supremacy is gone, and practically all housewives are using one or another of these wetting agents, in dishwashing, laundering of garments, or in shampooing their hair.

Chemical Additives in Foods

Time was, and not so long ago, when the thought of adding chemicals, especially synthetic ones, to foods was unthinkable. I can well remember the "poison squads" of my college days forty-odd years ago, when volunteer students constituted test groups for determining the physiological effects of sodium benzoate when used as a preservative, and sulfur dioxide as a bleaching agent. Harvey Wiley was campaigning for governmental control and was rightly successful in winning his crusade, with the result that we have adequate control of the use of chemicals as food additives, contrary to certain sensational articles that have recently been appearing, and the unsupported statements of some witnesses who have been testifying before the House Select Committee investigating this matter. There is no evidence that chemicals now added to foods, preservatives, flavoring materials, bleaching agents, surface-active materials, and colorants, have produced injury, or that the present law is not adequate to protect our food supply.

Practice under the present law has been excellent. Tremendous sums are spent by the chemical and food industries and by the governmental agencies responsible in this field to see to it that the public is fully protected. Our food products today are better because of chemical additives. There must be no unnecessary restraints upon further improvement in foods through the use of additives—restraints that would stifle research and progress in this field. We are not being poisoned by "Perils on Your Food Shelf," as Representative Delaney would have us believe.

Petroleum Additives

These will be only briefly mentioned as they have been covered in the paper on "The Petroleum Industry." Suffice it to say that the chemical industry is supplying enormous quantities of cracking catalysts, detergents, antiknocking agents, antioxidants, pour-point depressants, corrosion inhibitors, grease ingredients, and additives for high-pressure lubricants. Many of these are organic sulfur and phosphorus compounds. These have contributed importantly in our production of the finest fuels and lubricants made today.

Chemotherapeutic Agents

I would not have adequately covered my alloted subject if I did not make at least a reference to chemotherapeutic agents and emphasize the chemical industry's vital contributions in this field.

Though Erhlich discovered the therapeutic value of Salvarsan in the early part of this century (1910), little advance in the use of synthetic chemicals in the treatment of disease was made until the discovery by Domagk of Prontosil in the middle 1930's and the recognition shortly thereafter that it was the sulfanilamide portion of the sulfa-dyestuff complex that was the antibacterial agent. A few synthetic products were in common use as drugs prior to that time—acetanilide, phenacetin (acetphenetidine), aspirin (acetyl salicylic acid) and other salicylic acid derivatives (sodium and methyl salicylates), antipyrine (a pyrazolone), the chloramines, and phenolphthalein, as were also the barbitals and novocaine—but the additions to the list came slowly. The discovery of the sulfas and their remarkable efficacy in combating certain germ-produced diseases stimulated concentration of research effort in this field. One after another sulfa appeared, some of lower toxicity to the host, others effective with other organisms, or with more organisms. Some of the earlier sulfas have become obsolete replaced by such effective ones as sulfadiazine, sulfathiazol, and sulfamerazine.

The chemical industry is producing, among many other medicinals, most of the vitamins, including folic acid and nicotinic acid, cortisone, *p*-amino salicylic acid (for use with streptomycin in the treatment of tuberculosis) and propylthiouracil for controlling the metabolism of thyroid patients. The chemical and pharmaceutical industries believe that the future in this field is almost unlimited and are pouring money into research at a rate which I believe exceeds that in any other area.

CONCLUSION

The importance of an industry to human welfare cannot be measured in dollars, of capitalization, or of sales, or of profits, but it is significant that within a period of less than forty years, the American chemical industry has grown from a mere infant to the point of being the largest industry in the country, larger than the automobile industry, larger than steel. Its laboratories are among the largest and best equipped in the world and probably exceed in number those of any other industry. I believe it is safe to say that the chemical and allied process industries employ in research, development, and manufacturing operations, more scientists and technical people than any other industry and, over all, expend a larger percentage of their sales dollar on research.

The continued growth and success of the chemical industry, as in the case of many other industries, depend on its ability to obtain trained chemists, physicists, biologists, and scientists in many other fields, as well as engineers (chemical, metallurgical, mechanical, and other categories). There is a serious shortage of such trained personnel. Fewer students are entering college, and the percentage electing science and engineering has fallen off—this at a time when the demand is at an all-time peak. It is almost inconceivable that in this serious situation the various branches of our Department of Defense are inducting many scientists for use in jobs that do not require scientific skill or do not fully utilize their scientific competence. No other nation is squandering its scientific talent in this way. Proper realization of our war mobilization objectives demands that these men remain in their profession, either in our educational institutions, in industry, or in the military services. To do otherwise is to jeopardize the security of this nation. As General of the Army Douglas MacArthur said recently, in advocating tighter civilian curbs on the army: "Extension of civilian controls calls for a reassessment of the role of the citizen soldier now to become the major element of our military establishment during peace as well as during war. It calls for a realistic appreciation of the potential in professional competence which the citizen soldier can bring to the fulfillment of our military policy and aims."

The American Association for the Advancement of Science, in forming this new section on industrial science, is making, in my opinion, a notable advance. It is recognizing that the application of science and of the scientific method is inseparable from science itself. It is acknowledging that our industries in their research laboratories are large contributors to the advance of fundamental knowledge. It is providing, as does the American Chemical Society for chemists, a forum where scientists in *all* branches of science may meet on a common ground for exchange of ideas on basic and applied science. It is well that the Association has taken this step, and I am happy to have had a part in inaugurating this program.

The Pharmaceutical Industry

ERNEST H. VOLWILER

President, Abbott Laboratories, North Chicago, Illinois

THE pharmaceutical industry, as we know it today, is barely thirty-five years old. It is true that prior to 1915 the applications of bacteriology, chemistry, and pharmacology had led to important progress in our knowledge of immunology and of drugs of natural origin and several synthetic drugs had been produced which today retain the original high esteem in which they were held. However, the majority of the great advances in the production of drugs have been compressed into the last thirty-five to forty years.

These developments have brought with them a much greater awareness of health and physical well-being. All our prized assets are closely related to, and often stem directly from, the condition of our health. Broadly speaking, our status as a nation depends on it, and many of the political, social, and economic problems of the world and the maintenance of peace between nations are related to their degrees of health and to the control of disease.

So it is that we who are engaged in the pharmaceutical business feel that we are most fortunate. We have the fun of doing business in its various phases, including the making of a profit, and at the same time we have the encouragement and the lift that comes when a drug saves a life or removes some of its pain and discomfort.

During the early 1930's some men in high government places held the philosophy that business had reached its horizon and that we should all consolidate what we had and adapt ourselves to a gradually declining economy over which the government would wield an ascending degree of control. The falsity of this defeatist philosophy was evident then, and it has since been disproved time and again. True, our geographic frontiers are largely gone, but invention in science and in engineering has more than made up for them. Since the virility of the pharmaceutical industry is based on a continuing flow of new ideas put to practical application, it can be used as an example of what has been accomplished and what may be expected of our economy.

The great medical advances of recent years have been due in part to a better understanding of disease, in part to better surgery, and in large degree to better medicinals. As recently as 1925, the number of highly potent and really effective drugs was quite small. Physicians had quinine for malaria and the new arsphenamines for syphilis, but most drugs were used for the relief of symptoms. Chemotherapy, that is, the direct attack on invading organisms by chemical agents, had excited the deepest interest when Ehrlich announced his discoveries, but the efforts of scientists during the following twenty years led to only a limited number of valuable chemotherapeutic compounds.

RECENT DISCOVERIES

The belief persisted that medicinal agents could alleviate symptoms of many diseases, but only the body itself could cure the malady. Then a series of electrifying discoveries were of such deep interest to nearly everyone that at times laymen came to speak of disease and drugs almost as glibly as the doctor and the medical scientist. The story is told of a lady who came to see her physician. After an examination he said, "You are somewhat run down. I had better prescribe some vitamin B_1." She asked, "You mean thiamine hydrochloride, Doctor?" He inquired, "Is that what they call it now?" Although the layman today has a much more accurate knowledge of how to guard his health, and even though he often jumps to unwarranted conclusions and is sometimes misled by articles in high-geared magazines, he relies more regularly on his family doctor who, in turn, is better equipped by training, tools, and drugs to take care of the patient's needs.

Hormones

It is natural that when a successful discovery is made in any field much research is directed at once into that channel. So we have seen concentrated attention given to hormones, of which epinephrine, thyroid, and insulin were early examples. Development of this field has continued through the years, leading most recently to the spectacular ACTH and cortisone. The functions of the body are complex, and they are regulated by many hormones and enzymes which differ widely in chemical nature, as well as in physiological function. Many of our body processes are subject to regulation and control by minute quantities of these agents. We appear to have made just a good start in this fruitful though difficult area.

Vitamins

Then came vitamins. Their use for the cure, as well as for the prevention, of nutritional diseases has become so firmly established that no well-informed person should remain a skeptic. When vitamins were synthesized and became available at much lower cost, the control of many of these deficiency diseases became possible. Even in poverty-stricken India and China, beri-beri and pellagra can be prevented and cured by fortifying rice and other foods with small amounts of thiamine and nicotinic acid at low cost. Apparently most of the important vitamins, but not all, have now been discovered and put to good medical use.

Sulfonamides

Hope that the conquest of bacterial disease could be accomplished by chemical means received its great impetus when the sulfonamide drugs were discovered in the 1930's. The first of these, sulfanilamide, had been known as a chemical compound for about fifty years; yet, until its antibacterial power became evident, it appeared to be only one of the relatively useless synthetic compounds which some curious chemist had once made and put on the shelf because no one had suggested a use for it.

The fast-developing series of sulfonamides had a deep impact on the practice of medicine. Just before their discovery, many diseases due to bacteria and protozoa were among our leading causes of serious illness and death—pneumonia, septicemia, venereal diseases, and many others. There were no less than thirty-two known types of pneumonia alone, each requiring its own specific type of antitoxin for treatment. The sulfonamides have changed all that. Pneumonia, as well as septicemia or blood poisoning, have ceased to be highly lethal diseases.

Penicillin

Hardly had the medical world ceased to marvel at the potency of the sulfa drugs when penicillin burst on the scene. Before discussing the antibiotics, let me say that their use has been superimposed on the use of the sulfonamides; the latter continue to be used very widely, and for many purposes the antibiotics have not replaced them.

The production of penicillin and of the antibiotics which came along later necessitated the development and use of equipment much larger than the pharmaceutical industry had ever needed before. Fermentation tanks in sizes up to 20,000 gallons and larger, complex fractionating equipment making use of the very latest engineering principles, and sterile manufacturing operations on a previously undreamed of scale—all these have grown along with the mass growth of the tiny penicillin-producing molds. The improvements of the strains of the organisms by the microbiologist, plus chemical and engineering advances, have caused the unbelievably steep reduction in the cost of penicillin. In 1943, 21 billion units were produced; and the market price was $20 for 100,000 units. In 1950, almost 300 trillion units were produced, and the bulk market price was 4.5 cents for 100,000 units. In fact, the cost has been reduced so far that in some packages the cost of the penicillin in a bottle is less than the combined cost of the bottle, label, and carton.

And still the production and demand are increasing. The thirteen

American manufacturers are now producing almost 30 trillion units per month, an amount which is equivalent to more than 200 tons of pure crystalline penicillin salts per year.

Other Antibiotics

To the large quantity of penicillin must be added the production of other antibiotics which supplement penicillin. Streptomycin is quite specific for tuberculosis; chloromycetin, aureomycin, and terramycin are all used in large volume because they successfully attack certain bacterial, rickettsial, and even virus diseases in which penicillin is not effective enough.

From the standpoint of value in dollars, antibiotics are the most important single medicinal field. Sales in 1950 were valued at 214 million dollars as compared with a value of about 350 million dollars for all synthetic medicinals. Absorption of this greater output is possible because larger doses than formerly are being used, and considerable amounts of the antibiotics are used as animal feed supplements. This latter application, which results in a 10 per cent to 15 per cent increased gain in animal weight, can be a factor of far-reaching social and political significance in world affairs. A better fed world population, especially with regard to proteins and fats, may possibly become more reasonable and less belligerent.

What of the future? There are many firms carrying on an active program of research to develop new antibiotics. There is no question that valuable new ones will be discovered. Some of the important antibiotics of the future will be specific against certain diseases not now satisfactorily managed by what we already have.

FIELDS FOR NEW ANTIBIOTICS

New antibiotics, comparable to those we already have, may find definite fields. Bacteria are versatile organisms. By changes or mutations, some of them can adapt themselves to the agents to which their ancestors easily fell prey. Also, sometimes one predominant strain of bacteria may be eradicated, leaving the field open for an obscure resistant strain which previously had not been important. The battle against pathogenic bacteria is thus an eternal one. As in warfare between armies of men, our warfare against bacteria will require the continual development of new weapons.

An antibiotic for tuberculosis which will be better tolerated than streptomycin or an antibiotic effective against some of the virus diseases are goals which justify the efforts of hundreds of scientists and the expenditure of millions of dollars. The opportunities and the chances for success in these directions are quite promising, though one cannot tell when nor where this may occur. To discover a new antibiotic in the laboratory is now quite easy, but to produce one which will have all the qualities of high efficiency with relative freedom from undesirable side actions is not easy. It represents continuing unremitting research, but if such research is continued long enough, the chances of success are good.

OTHER CONSIDERATIONS

The pharmaceutical industry has contributed much to surgery by means of the anesthetic and analgesic agents which it developed. Today we have available local, general, and intravenous anesthetics whose use by improved techniques makes operative procedure a far cry from that of a quarter century ago.

It is estimated that up to 5 to 10 per cent of our people suffer in varying degree from allergic conditions, hay fever, urticaria or hives, and others. The discovery within the last ten years of the antihistamines has given us extremely useful agents for the control of these conditions. Today there are several dozen good products available, all somewhat similar in action but having some differences in effect and in duration of action. Some persons respond better to one than to another of these synthetic compounds.

Many other fields of medical practice have benefited from newer drugs, such as the antithyroid compounds; drugs which will prevent blood clotting, and others which will cause it to clot; and synthetic compounds which control the seizures of epileptics and permit them to lead more nearly normal lives. Blood has been commercially resolved into its valuable components, and the so-called blood expanders, Dextran and PVP, give promise in the treatment of shock, although they are by no means complete substitutes for blood itself.

Even the development of the atom bomb has left a marked impression on the pharmaceutical industry. Radiation effects require blood, blood expanders, penicillin and other antibiotics, and a score of other drugs. While we are studying these potential needs, let us hope that this particular demand will not occur; but there is a more encouraging and interesting aspect to the by-products of the atom bomb.

The radioisotopes have become important tools, both for the diagnosis and treatment of disease. Now we can introduce one of these products of the atomic pile into various types of compounds. Their course in the animal body can be accurately followed and the mode of action determined. Often these isotopes concentrate in one organ much more than in other organs.

For diagnostic procedures, radioactive iodine in the form of diiodofluorescein becomes localized in brain tumors. The surgeon can thus accurately know where the tumor is and where to operate. The physician sometimes needs to know the total volume of blood plasma in the body. He can now obtain this information simply by the injection of an iodine-tagged "human serum albumin." Radioactive sodium can be used to determine the causes of the edema in congestive heart failure. Penicillin can be tagged, and when a trace of this compound is added to the contents of a large penicillin fermenter, we have an excellent, economical, and quick way of determining how much penicillin we have in the batch. Radioisotopes are even being used to tag bacteria so that they can be located in various tissues of the body.

Radioactive iodine is of direct use in the treatment of cancer of the thyroid; radioactive phosphorus against leukemia; and radioactive gold for the treatment of ovarian tumors. This radioactive gold gives emanations which penetrate tissue for only short distances, permitting the effect to be more nearly localized to the cells in the tumor which one wishes to destroy.

CONTRIBUTION OF RESEARCH

Since the pharmaceutical industry has been indebted to research for the important advances of which I have mentioned some examples, it is appropriate to consider the yield from research. One of the characteristics of this industry is the large sums spent for investigation. The rate of expenditures per dollar of sales amounts to about 3 to 5 per cent and is probably larger than that of any other important industry. The fact explains the rapid advances in medical treatment, and it also explains the rapid obsolescence of products. A survey made in 1947 indicated that 54 per cent of drugs then in use were unknown ten years earlier. In the case of my own company less than 25 per cent of today's volume of products is made up of items which were known ten years ago. In an industry which moves so fast, research must receive great emphasis for a firm to stay in the race. It has been said that we have to do research to obsolesce our own products, lest a competitor do it for us.

Research is a gamble, but if it is well conducted it is a gamble that has very good possibilities of paying off in one way or another. In our industry, doing without research would involve no gamble at all because the company would soon be out of business.

If we set out to produce a new drug, our chances of coming up with a successful one are perhaps one in three hundred. It is obvious that a great deal of testing or screening must be done on many compounds in order to find one whose efficacy, toxicity, and tolerability are all sufficiently good.

Where do these new ideas for drugs come from? Seldom do they come about by pure chance. Often they are the result of the logical development of a train of reasoning. Sometimes they come by serendipity. The principle of immunization, the principle of the drugs used against epilepsy, and the principle of induced sensitization on which the treatment of allergies is based are a few examples. Even Fleming's discovery of penicillin is in this category. He was looking for some new properties of bacteria when the stray mold spore blew onto the plate and thus started a revolution in the treatment of infectious disease.

EFFECTIVENESS OF MODERN DRUGS

It is evident that today's drugs are much more effective than were those of years ago. By reason of their greater potency, many of these products must also be used with greater care, skill, and circumspection, lest they do serious harm to the patient. The physician is aware of this, and he is better trained and experienced than ever before in the use of such active products. In years gone by, many crude extracts of plants did little good for the patient, but they also had little potentiality for harm. But now, the life-saving sulfa drugs, or insulin, or cortisone, or even the antibiotics must be used wisely and with a realization of their potential harmful effects when misused. The trend is largely in the direction of highly effective drugs which, by their very nature, are capable of causing harm.

LEADERSHIP OF THE UNITED STATES

Prior to World War II, 75 per cent of the world's drug products were produced outside the United States. Now the world not only relies mainly on our medicinals, but it looks to the United States as the fountainhead from which a large proportion of the new developments will come. It is my conviction that this supremacy will not be wrested from us, because the pharmaceutical industry is willing and anxious to spend large sums of money for research, development, engineering, and equipment and also because the chemical and biologic sciences appeal strongly to the bright young men and women who come out of our colleges and universities. They infuse new blood, new imagination, and new energy continuously into our industry.

The population of our country is growing at the rate of about 2¼ million persons annually. The groups of those under 10 and those over 50 years old are increasing considerably faster than the population as a whole. Since young children and older people require more medical care than those whose ages are between, the requirements for drugs will rise still farther.

The public is also becoming more conscious of the value of medical care. Hospital admissions increased more than 120 per cent from 1935 to 1951, while the population was increasing about 20 per cent. Also, our people are better able to provide for medical care. Voluntary health insurance now covers half of our population, as contrasted to only 5 per cent in 1939. This fact itself is at least a partial answer to the mistaken proposition of socialized medicine, whose large-scale trial in England can hardly be called successful or promising. At the same time, there has been an appreciable relative decline in the costs of medical care, including drugs. The U. S. Bureau of Labor Statistics shows that clothing costs in June, 1951, were 104 per cent higher than the 1935–39 average, house furnishings 112.5 per cent higher, and recreation 68.3 per cent higher. Medical care costs, however, were up only 54.7 per cent.

The pharmaceutical industry is not large, in terms of our largest industries. In the United States, expenditures for drugs in 1950 were approximately 1.5 billion dollars, or less than 1 per cent of the consumers' disposable net income. This amounts to about $10 per capita. Hospitals took $1.8 billion, doctors $2.3 billion. By way of contrast, tobacco took more than doctors and drugs combined, and alcohol took twice as much.

NEW HORIZONS

As diseases are conquered, new horizons appear before us. When we have diphtheria, septicemia, tuberculosis, and other bacterial diseases well under control, our fire will be directed even more against the diseases we now call degenerative, including cancer, diseases of the heart and of the circulatory system, arthritis, and nephritis. There is no reason why they too should not yield to medical advances including therapy with new drugs, so that our children and grandchildren may live for a longer time in a state of buoyant good health. The pharmaceutical industry is at work to bring this about.

INDUSTRIAL SCIENCE TOMORROW

Horizons in Industrial Science from the Viewpoint of the Consultant

LILLIAN M. GILBRETH
President, Gilbreth, Inc., Montclair, New Jersey

ALL industrial engineers today are faced with the problem of understanding international developments in the field of scientific management and of cooperating in every possible way to solve them. Many are being invited abroad under the sponsorship of Economic Cooperation Administration. Many more are being called upon to welcome, teach, or orient industrial engineers from abroad who are visiting this country for short or long periods.

THE INDUSTRIAL ENGINEER

The term industrial engineer needs defining. In the exact sense, he is a trained graduate engineer who has specialized in industrial management. In the less exact sense he is a person who performs the functions of an industrial engineer, but who may have been trained in business administration, in commerce, in economics, in psychology, or in some other discipline. It is to be hoped that he has had training in solving industrial problems and experience in industry. The industrial engineer is supposed and expected to have had some shop experience, as much of his work lies in industrial plants. Even an industrial engineer working on an office, farm, home, or hospital project profits by shop experience. It is to be hoped that he has not gotten this at the expense of training in human relations and the sciences that consider these. He is expected to have a sense of spiritual values, a philosophy of life, ethical standards, a general education, technical training, an understanding of human nature and an ability to get on with people, including knowledge of the art of communication.

THE CONSULTANT

The consultant is expected to have supplemented this training with a diversified experience in a variety of industries. His clients have a right to expect him to bring to their problems experience in solving similar problems, both in similar and in dissimilar industries. He should be able to know which problems are usual, which unique. He is supposed to know resources and to bring them quickly to his client's attention. While he represents himself or his firm as a consultant, he should identify himself with his clients, and he is pledged to try to find and solve their problems and advise on new procedures.

It is because of his training in accepting these responsibilities that there is an increasing demand and an international demand for his services. Some industries prefer to have their own industrial engineers rather than to use consultants, but the procedure these engineers follow is increasingly like, rather than different from, that of the consultant. The consultant has the advantage of continuing diversified experience and an objective viewpoint. He has the disadvantages of less intimate contact with the client's plant and personnel and often more pressure to get results. The wise consultant studies what is expected of the plant's own engineer, and, if wise, he studies what the capable and satisfactory consultant does.

IMPORTANCE OF TEAMWORK

The consultant must increasingly prepare to act as a member of a team. This requirement permeates every aspect of his professional life. He may be a specialist or a generalist in the firm to which he belongs. That firm itself may specialize or generalize. There is great variety here, and there is likely to be even greater variety. Some firms take assignments that demand knowledge of how to apply all the principles of management and administration and also experience in applying all available techniques. Others do not handle some of the techniques, such as work simplification and quality control, but advise their clients to employ specialist consultants in these fields or send their own men to be trained in courses increasingly available for this purpose. This does not mean less teamwork but more, for all the services that the client is using should be integrated.

If the consultant is a member of a large firm, he may or may not be called upon for special techniques or skills. If he is, he must be careful not to lose sight of the complete problem of the client. If he is not called on, he must be careful not to become so much of a generalist that any special interest training or experience he has had will remain unused and decrease in value to him and to his organization.

THE CONSULTANT'S RESPONSIBILITIES

The consultant, usually through his firm, is a part of the professional societies and associations in his field: the international management society, Comité International de l'Organisation Scientifique (CIOS), the National Management Council, the American Society of Mechanical Engineers, The American Management Association, The Society for the Advancement of Management, and many others. He may be called upon by his firm to present or discuss papers and to participate in panels, round tables, work shop sessions or other opportunities the programs of the various societies offer to contribute to his firm's experience. He may, on his firm's time or on his own time, accept committee appointments or make other contributions to the society's work. He may attend meetings that will profit him directly and his firm indirectly, through his greater effectiveness. He is fortunate if his firm realizes that it is an honor and a privilege for any of its members to give international, national, or local service to a society and frees him to give the time and energy needed, with no loss to himself of any kind. This implies fine teamwork, for his regular job must be handled by others, and he must be fitted back into the schedule on his return, with adjustments not always easy to make.

Consultant firms not only must practice teamwork within themselves but also with one another. An increasing number have foreign affiliates or associates. This brings challenging problems, both at home and abroad. In spite of air travel, the long distance telephone, air mail, etc., it is difficult to check constantly on all the problems involved, from codes of ethics, up and down, i.e., beliefs, policies, and practices. This difficulty seems likely to become greater rather than less, unless an expansion of the activities of CIOS is adequately supported in interest, money, time, and energy. Naturally we can hope that ultimately fine teamwork will result, especially if the fine General Secretary of CIOS continues his work.

On the job itself the consultant is a member of a team which includes representatives of every group with whom he works or should work. He may not be able to set up this team single handed, but he should convince his client that such a team is vital to the success of his work. This is one reason why top management must know what is to be done and its part in getting it done. If the consultant strengthens teamwork in his client's organization, it is a great asset. If he weakens it, it is a great liability.

THE CONSULTANT AND A NEW TEAM

We have already indications of a new kind of team of which the industrial consultant is a part. This is a team representing all the disciplines that can contribute to the solution of a problem, such as engineering, physiology, medicine, psychology, psychiatry, sociology, economics, and biomechanics, as well as mathematics, physics, and chemistry. It has long been recognized that all groups which handle "nature" must work together. The new thing is adding to this group those who deal with the handling of human nature. Starting to cooperate on a national level, these increasingly cooperate on an international level. They also cooperate on a job level, where representatives of each area of interest team with each other to contribute resources. An industrial engineer may channel the resources of all branches of engineering; an industrial physician the resources of all branches of medicine; an industrial psychologist the resources of all branches of psychology. It is vital that we realize that continuing and increasing resources imply fundamental research. On this rest all plans for widening horizons.

The consultant who can rely upon and draw from resources of all appropriate disciplines thereby joins and utilizes a more powerful team than his predecessors realized could exist. With such resources the industrial engineer can go into new fields—into libraries, schools, hospitals, work for the disabled. He can hope to make his services available to men and women everywhere, because he or the members of his team can see, state, and solve problems adequately and with satisfaction to everyone.

Horizons in Industrial Science from the Viewpoint of the Educator

JAMES CREESE

President, Drexel Institute of Technology, Philadelphia, Pennsylvania

INDUSTRIAL science is a happy and convenient phrase. It describes an area of knowledge and discipline which is now peculiarly promising, as broad as science and as productive as modern industry. In this area, still inadequately surveyed, there is work to be done by schoolmen for which we have but few precedents.

Until a little while ago, this term "industrial science" would have been challenged by many scholars as a contradiction in terms. So might it have been by the industrialists themselves. The scholar, in his professional capacity as a scholar, was thought to be, by definition, "indifferent to the effect and use of the truth" revealed in his studies. He kept a place remote from the factory and the market. His absence was not commonly lamented by businessmen, factory managers, and workers. Industry and trade did not presume to be scientific, and science was definitely not industrial.

In 1951, for the first time in the 103-year history of the American Association for the Advancement of Science, the term industrial science has been affixed to an officially organized Section of the

Association. But anyone who reviews the programs of annual meetings through several decades will find that there has been a gradual infiltration of industrial science year by year, a steadily growing volume of just such papers, lectures, and seminars as will compose hereafter the program of this new Section. There is nothing new except the formal identification of industrial science as one of the eighteen major fields of the Association's interests and activities. This year's inauguration of an eighteenth section and a sectional program on industrial science is just a well-timed recognition of a *fait accompli.*

INDUSTRY ACCELERATED BY SCIENCE

Today the words "science" and "technology" are on every page of current history. We speak the two words almost in one breath. Their alliance is so generally acceptable and mutually profitable that in everyday speech we often fail to make a distinction between the two words.

Perhaps the new phrase "industrial science" will relieve us of an ordeal in semantics and permit us to recognize frankly the fact that every enterprise of science is of practical significance in our economy.

Science has permeated our entire industrial structure. No company and no community can dare to neglect the advancement in science of its own industrial interests.

In speaking of industrial science from the point of view of the petroleum industry Mr. Wilson of the Standard Oil Company of Indiana estimated that, within that one national industry, as much as $100,000,000 is now being expended annually on research and development, forty times as much as was spent for such purposes in 1916. Beside Mr. Wilson's estimate of what is spent today on a national scale by the petroleum industry, I would quote an estimate of the overall appropriations for the conduct of research and development by corporations located in the Philadelphia-Camden industrial area, in just about a dozen counties of Pennsylvania, New Jersey, and Delaware: not less than $75,000,000, perhaps as much as $100,000,000.

The figures for the nation as a whole, for all industrial areas, for groups of corporations and allied industries, both within the companies themselves and by contract with research institutes and universities, are of astronomical dimensions. Better fuels, better foods, better shelter, better medicines, and an infinite variety of better goods and better services are the result.

The consideration of better profits, too, and the desire of each company not to be outdone by its competitors may conceivably have prompted the recent acceleration of industrial science. But in this vast expenditure of effort, time, skill, funds, and laboratory resources, research by competent and imaginative men cannot long be restricted, nor will perceptive and discerning management keep it severely restricted to appointed problems of invention and discovery which will obviously yield an advantage in competition. Not a few of the research departments maintained by industry have reached beyond the borders of their immediate corporate interests. Better progress in science, therefore, is a result to be expected, all along the line, in applied science, of course, but also in what has been called pure science.

THE EDUCATOR'S DILEMMA

Anyone responsible for recruiting a faculty in any field of science must recognize now that universities and industrial companies are engaged in a kind of competition, a very real and perhaps dangerous competition for the services of scientists. Opportunities are offered in industry which it is not often possible for the colleges and universities to match: higher salaries, of course, but exceptional research facilities, too, and the very associations with scientists of superior quality who earlier might have been met only on a university faculty.

Modern research departments established by industry often look like universities. The buildings may be arranged as on a campus. In the laboratories of industry now are some of our best known scientists and scholars. Such men attract disciples.

The only persons missing are the undergraduate students. That is where the danger lies, even a danger for industry itself; for as the best and most promising men are drawn away from the universities and into industrial laboratories, there may be a dearth of scholar-teachers. Who will then discover, select, inspire, and instruct those young men who in their turn must control the great plants for industrial research and industrial production?

There is a pressing need for an alliance and a working arrangement between industry and the schools, a partnership not only in advancing our knowledge of science by mutually advantageous research, but also in selecting and training the research men and the managers who will operate our great industrial plants in the future.

THE EDUCATOR'S OPPORTUNITY

As I consider the horizons in industrial science, I find myself tempted to revert to an old phrase that has graced many an after dinner speech: "challenge and opportunity." Industrial science offers both to all our schools.

I see first the opportunity that may be given to a school by a close contact of its laboratories and its faculty with the laboratories and research staff of a great, alert, successful industry. We might exchange men at times, as we at Drexel Institute of Technology send students back and forth between academic laboratories and industrial plants. We need always to exchange ideas, and there are innumerable scientific and technical problems in industry to provide a stimulating and rewarding experience for the men of a college faculty.

One of the familiar and useful channels of interchange between industry and education is in the services of consultation and research for which the specialists on the academic side are brought into association with their colleagues in industry for the development of new tools, processes, and principles. By that means the instructor in the classroom gains case materials which could not be obtained otherwise. Or for himself and two or three disciples, post-graduate students, he may carry back to the campus some few challenging problems of research. But valuable as such cooperation in research is and can be, it is not by this means that an institution of learning makes its unique contribution in the advancement of industrial science.

The unique contribution which colleges and universities make to industrial science and which no other agency can make is in the selection and instruction of students of today to make of them the scientists in industry, the engineers, specialists, and professional leaders in industry tomorrow. In this great task of selection and training, the institutions of higher learning and industrial companies have a vital common interest.

The acute need for competently chosen and technically qualified young men in industry and the armed services is at this moment a matter of national concern. We are all of us acquainted with the statistics compiled during this past year by the engineering and scientific societies on present and future manpower needs and on our inability to meet the impending shortages with the anticipated numbers of graduates in the basic sciences, in engineering, and in other specialized fields.

The statistics present the problem quantitatively. The problem can also be stated qualitatively. In our economy, so highly industrialized, so dependent on our ability to hold our own in scientific and industrial developments, no short cuts in education can be allowed; nor can we afford to let our educational institutions get along as best they can with the second best in personnel, equipment, and facilities. If our manpower is not to be wasted, if industrial output and a high standard of living are to be maintained, if social unrest is to be avoided, then school generation by school generation must find in business and industry full opportunities to develop their best abilities and to secure the durable satisfactions of life.

A short time ago I had occasion to visit about a dozen universities and colleges of technology in Great Britain and the Scandinavian countries. I was soon aware of a deep concern in Great Britain, on the part of British industrialists, for the improvement of British higher technical education. At the close of World War II a formidable committee of public persons, scholars, scientists, engineers, and men of affairs, the Percy Committee on Higher Technological Education, was appointed to review the shortages of technically trained men that had been disclosed by the war. One of their conclusions, one that surprises an American and impresses him as being especially significant, is the statement that British industry does not get its full share of the best product of the schools. "At present," said the Percy Committee, "too large a proportion of the best output of the schools goes into non-industrial occupations." And again, "The position of Great Britain as a leading industrial nation is being endangered by a failure to secure the fullest possible application of science to industry; and . . . this failure is partly due to deficiencies in education."

We need to remember, in America no less than in Great Britain, in wartime no less than in peacetime, that the modern school system, not less in the colleges and universities than in any other part, has among its essential public duties the double task of selecting and training the working force of an industrial economy. Unless alert and imaginative young men and women, well chosen and well instructed, are made ready in great numbers for the administration of industry, then an industrial economy will fail and an industrialized democracy will either cease to be industrial or it will cease to be a democracy, or both.

IN A PERIOD OF MOBILIZATION

American boys of college and university age are now caught up in world conflicts which will inevitably interrupt or prevent their education.

If we had to face nothing but a quick campaign or war and knew that the crisis could be disposed of by prompt, harsh action, we could wisely put into uniform and into service every young man capable of going. This country may yet be obliged to do that. But more to be expected is an indefinitely long period of partial activity and mobilized waiting, when vast numbers of our young people will be called from their employments and their schools to camps, cantonments, and military installations at home and abroad. They will learn the meaning of an old military saying that the Army must "hurry up to wait!"

In this situation, industry and the universities may find opportunities for a new kind of collaboration. By the fall of 1951 some fifty-three colleges and universities had set up classes in military posts and camps, with a total enrollment of 27,000 students-in-uniform. But of the courses offered, few, almost none, touch basic or industrial science. Libraries are lacking. There are no laboratories and no laboratory equipment. As mobilization extends or if Universal Military Training is actually begun, a stoppage of education, dangerous to all progress in industrial science, may occur.

This risk lies in the immediate foreground of the education scene, not off on the horizon. And I think it offers an opportunity for joint action by schools and industries. If industrial science is not to lose large numbers of able high school graduates, industry and the colleges must work out with the military authorities some effective means of identifying boys capable of continuing their studies in mathematics, the basic sciences, engineering, and industrial administration and give them a start even during their period of military service. We shall have to develop, too, a satisfactory means of making it economically possible for these young people to continue their technical and professional education after separation from the services.

In World War II, there were referred back to colleges thousands of men in uniform for specialized training. When the war was over, a couple of million young veterans were sent back to college under the G. I. Bill of Rights. The industrial and public significance of these wartime and postwar provisions will be suggested by an answer to just one question: In what predicament would we be if there had been then no effort to keep up a steady flow of men to the places where men of superior skill and complete training are now needed?

LOST MANPOWER

The military risks of education, of which I have mentioned only one, rise in the immediate foreground and may stretch all the way to the horizon. Within what may be called the normal provinces of education, there are similar continuing features of the landscape. I shall mention briefly three which are of concern to all interested in the advancement of industrial science and in the critical problems of scientific manpower.

1. In our grammar and high schools we have nearly 30 million

youngsters. Never before in history and in no other country has there been so glorious an opportunity to guide, appraise, instruct, and inspire an entire people, generation by generation. The job is being well done by too few teachers, overworked and underpaid. But in those schools some of high genius are lost, and many, even millions, may miss the touch of reality and clear purpose in their long years of school. When they ask "What's the use of my taking this course?" they deserve a better answer than "Mother knows best."

Frustration in school and failure in courses that seem, rightly or not, to lead elsewhere than to a place of real usefulness, may be a central cause of lawlessness and addiction to narcotics. Perhaps education in the lower schools must be of a general character, but there is sound reason why the teachers in those schools, particularly the teachers of science in the high schools, should have the direct and refreshing contact with industrial science which college teachers so much appreciate.

2. We must face the fact, too, that for economic and environmental reasons, many young people of real ability who could satisfactorily follow courses in higher education to prepare themselves for careers in industrial science terminate their education at high school or before they graduate from high school. Many move into dead-end employments in which their talents are never fairly utilized, with great loss to themselves and to the country. There is a joint task for industry and our schools to identify the young people already employed in industry who are capable of undertaking advanced technical training and to work out such programs of evening study and on-the-job study as will develop their best potentialities. With the cooperation of several hundred industrial companies of the Philadelphia area, we have long conducted such work in the Evening College and Diploma School of Drexel Institute of Technology, and with notable success.

3. In adult education, there are prime examples for industry in our countrywide system of agricultural extension. Agricultural extension has not followed a shoddy, unscholarly, one-track course. It has touched every part of life on the farm. County agents carry from the universities and the experiment stations directly to the

farms all the influences of research and development in agriculture. No such contact with science and technology is given to city populations, again with great public loss.

INDUSTRIALISM AND HIGHER EDUCATION

I do not mean to imply that American schools and universities have failed in their task of training our young people for the roles which they must play in an industrial democracy. American higher education has been exceptionally sensitive to the changing needs of the times. It is sensitive now to the growing need for men and women qualified in the field of industrial science.

The industrial revolution, intensified and accelerated by the alliance of science and technology, had a profound effect on our economic, political, social, and educational institutions. Our entire school system has changed. The scheme and design of liberal education has been altered, so greatly altered as to make inadequate and incomplete any definition of liberal education or of general education for life in a free society, if in that definition there is not a reasonable emphasis on the industrial, scientific, professional, and vocational themes that are characteristic of our peculiar kind of civilization.

Revolutions in education regularly accompany political and economic revolutions. The economic forces have been at work which have radically changed the pattern of our life. These forces have left their imprint nowhere more clearly than on our system of schools and colleges. The organization and the processes of American industry were suddenly changed when mechanical horsepower replaced handpower, and when machines released men from the factory. The first to be released from long hours of daily toil were the children and the young people. At the time of the Philadelphia Centennial in 1876 there were not more than 70,000 students in all the high schools of the country. Today there are more than 7,000,000. A plan or concept of liberal education suited to a mere 70,000 had to be materially modified to meet the divergent interests of 7,000,000 as well as to meet the needs of the new industrial democracy.

Much as we have accomplished, there is still much to be done.

Schools of mechanical and industrial arts are of recent origin. Few of our colleges of engineering are more than seventy-five years old. Even the oldest of our undergraduate colleges of business administration, the Wharton School of Commerce and Finance, was established only in 1881. Drexel Institute of Technology celebrates this year the Sixtieth Anniversary of its founding in 1891. The American colleges of technology, business, and industry are all young. Small wonder that we have not yet satisfactorily defined the part which higher education plays in training college students for industrial responsibilities.

INDUSTRIAL SCIENCE AND DEMOCRACY

More is comprehended in the phrase "industrial science" than the matters of scientific research, basic and applied. A third component, likewise shaped by the method of science, is all that is described and all that could be described in a chapter on scientific management. Here, all the variables are not of a sort that could be subjected to standardized tests or run through a distillation process, for they are the variables of human nature, of individuals with individual personalities, hopes, fears, ambitions, similarities of importance and dissimilarities of greater significance.

Our ideal is to let each make the most of himself, to give that variety of opportunities for life, liberty, and the pursuit of happiness which will discover and satisfy the vast variety of human aspirations.

Two great dynamic forces run in our century and in our country, both relatively new, the force of democracy and the force of industrialism. Whether they run in conflict or together, each reinforcing and supplementing the other, is still the unanswered public question of our age. We have such control of the power of nature as has never before been put into the hands of men. Will we have wisdom enough, wit enough, persistence enough, and sufficient sense of history and of the mission of freedom to use our power well? The validity of our science in this age of industrial democracy will be measured in history not by the range of scientific thought or by the volume of production of the equipment of comfortable living but by the use we make of it to improve the lot of man, to make his mind and his spirit free.

Horizons in Industrial Science from the Viewpoint of the Research Institute

FRANK C. CROXTON

Assistant Director, Battelle Memorial Institute, Columbus, Ohio

HORIZONS are as real as tomorrow and as elusive. They hide what lies beyond, but they reveal the visible background. They introduce a mystery into the future of time and the distances of terrestrial space, a mystery which has challenged ancient and modern man to greater efforts of exploration and research. Research, in turn, furnishes the very basis for present-day industrial science. Research becomes more and more important to life itself on our agitated planet, whether to add to health and comfort or to postpone with fertilizers, pesticides, and improved plant varieties that Malthusian day of reckoning when the world's population overtakes its capacity to produce food by conventional means.

The research institutes of the United States have been faced since the first with horizons of varying clarity and at varying distances. It seems especially appropriate, therefore, to inspect industrial science from this point of view. Horizons are usually considered to be a limitation imposed by the post-Columbian spheroidal world. No less were the flat-worlders prior to 1492 limited by horizons both in fact and in fancy. To Aristotle, Descartes, and Leonardo da Vinci, such limitations were at great mental distances. In fact, even many of those who have since been proved wrong had admirable vision, if one considers their limited fund of knowledge and facilities for communication.

A horizon is really a rather useful concept. It forces one to define an area of activity which is within his capabilities, and yet it cloaks the hidden distance with a fascination which leads the pioneer on.

To look ahead in industrial science from the point of view of the research institute, we can draw with words a broad curve, based on the past and the present and extrapolated into the future. Its origin is well defined. Its future, within practical limits, is what we want it to be.

ORIGIN OF RESEARCH INSTITUTES

As with many innovations, the need for research institutes existed before they appeared. It was the perceptive thinking of Robert Kennedy Duncan followed by the outstanding research administration of Dr. Weidlein and his associates which established Mellon Institute of Industrial Research and brought it to its present position of eminence. Consider for a moment that prior to 1913 there was no such thing as a research institute. Consultants or testing laboratories were available, but versatile, well-staffed, well-equipped research laboratories of service to industry were not yet a part of the American science picture. In 1913, however, there was established Mellon Institute to conduct research on the fellowship plan for industry. During the ensuing thirty-seven years it has been of the utmost value to its donors who have received not only technical knowledge and completed developments, but also, in many cases, personnel of considerable ability. From this inception, the institute idea spread slowly at first but, since 1940, much more rapidly. Some, such as Mellon and Battelle, are clearly quite independent. Others, such as Armour and Stanford, are only loosely associated with universities, but still others, such as Ohio State and Temple, are university research foundations. All have the same objective: to conduct research for industry and for government agencies. Their rate of growth in numbers and size is a measure of their acceptance by a substantial cross section of American research management. Figure 1 shows graphically the composite growth of the four most prominent non-university research institutes of this country who publish budget figures. Realizing that only one existed until 1929 and that a number of smaller ones besides those of the universities have been added during the recent years brings out clearly the expanding area occupied by these organizations in the nation's industrial research program.

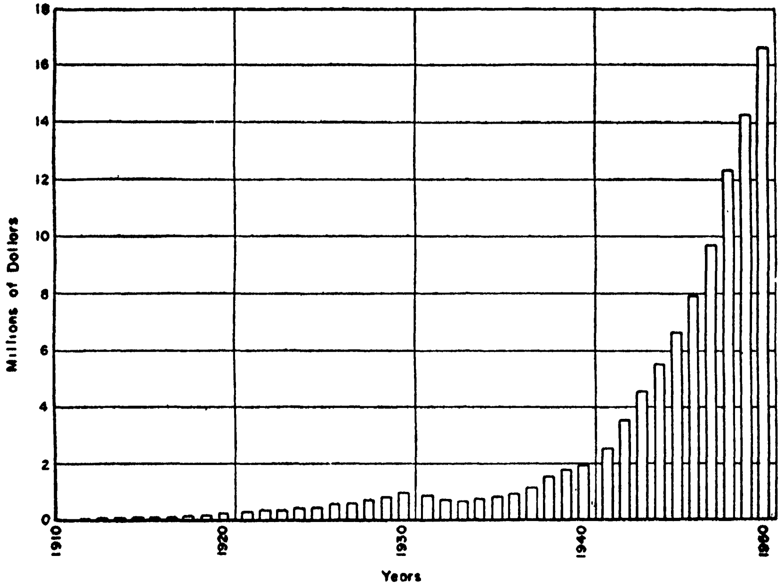

FIG. 1. Combined research volume of Mellon, Battelle, Armour, and Stanford research institutes.

What, then, has been the past performance of the research institutes? It has been said that they have grown, a process which must have been based on merit. In so doing they have staffed themselves with sound-thinking, but imaginative scientists, and have provided themselves with the tools of research necessary to meet the stringent requirements of an understandably critical cross section of American technical and management brains. They have brought themselves to the present in good order, but even now they are looking to the horizon and beyond into expanded time—their future and space—their scope.

CONTRIBUTIONS TO INDUSTRIAL SCIENCE

What have the research institutes done for industrial science? They have taken research where it scarcely existed before by making such facilities available to small- and medium-sized industry. No less, they have brought to the large companies, experienced in research, special equipment and talents, a temporary or preliminary look into a new field, or a fresh approach. There are numerous examples of newcomers among the industrial research laboratories who have based their methods of operation on the experience gained while sponsoring projects at a research institute. Industrial science has benefited from the investment to date of $102 million in the work of the institutes included in Fig. 1.

As for the record of the present to help us in our estimate of what lies beyond the horizon, it may be permissible to dwell a little on Battelle Institute. This independent, nonprofit institute began serving industry in 1929, in metallurgical research. Since it was entitled to enter related fields, it soon included ceramics, fuels, and ore concentrating. The most logical possible steps led on into other areas such as chemistry and agriculture. Battelle has grown from a very few people and a few thousand dollars in 1929, to a total staff in excess of 1900 and an annual budget of $9 million in 1951. Here the man with a vision was Gordon Battelle, while those with vision, technical genius, and a will to act included Clyde Williams, Oscar Harder, and the late Horace W. Gillett. Gordon Battelle could see an immediate need, this side of his horizon. Fortunately, he could see the services to be rendered in fields related to metallurgy. Fortunately, because it has enabled Battelle Institute to grow, thereby increasing its value to each industrial sponsor of research. In this institute with its permanent technical staff, the entire organization is available to solve each problem. The effect is to provide for a sponsor the type of research department which he would want if cost were not a consideration. Picture the value to a new-product-utilization investigation of forty-one integrated research divisions covering subjects from ore beneficiation and foundry practice to agriculture and the graphic arts. Picture, too, what can be accomplished in research aimed at the manufacture of a new synthetic organic compound with the combined efforts of specialists in organic chemistry, catalysis, high-pressure techniques, chemical engineering, corrosion control, metallurgy, instrumentation, and engineering economics. But, it may be said, that sounds expensive. Not at all, for the entire staff can work on a problem one man at a time, two men at a time, or as desired. The result is a finished job based on an intelligent approach and full-time professional execution. Does one wonder, then, that those who are associated with research institutes see them as important features of industrial science now and in the future?

Estimates of the volume of industrial research vary. Even definitions of what constitutes industrial research do not agree. It is believed, however, that its aggregate cost in this country in 1950 was $1000 million. Strictly speaking, this is not a cost but rather an investment. Rarely does a sponsor authorize a project without hoping for a many-fold return on his investment. In the course of sponsoring several such projects, his hope quite rightly becomes an expectation. It is the realization of this expectation which has led to the rapid growth of the institutes.

As a part of the present effort to peer into the future of industrial science, we should certainly reflect for a moment on the most important reasons for industry's use of the research institutes other than to benefit from their demonstrated technological productivity.

1. An enormous investment in research equipment is available to sponsors. In fact, since it is not feasible for an institute to undertake conflicting projects, each sponsor can count on having practically any of his contractor's equipment available for use on his project.

2. A similarly and perhaps even more importantly enormous investment in technical manpower and its brains are available to each sponsor. Few are the industries which could afford to staff their own laboratories with the 800 to 900 technically trained members of Battelle's staff of 1900. Fewer still would have the ability to steer their efforts toward maximum productivity. Not only an intelligent

and creative research staff, but also an experienced supervisory group can be depended upon to serve the best interests of each sponsor.

3. Economies in the cost of research can be realized at the institutes. This is accomplished not by cutting corners, not by using low-salaried personnel or by skimping in any way. Rather, it is done by means of an unusually high-quality research staff, supplied with the best of apparatus and working in congenial and pleasant surroundings. Battelle, for example, has capital equipment valued at nearly $5 million. It may be used by any project on a rental basis. How much more economical it is for the John Doe Company as a sponsor to pay only for the actual time of use of a rubber mill, a calender, an infrared spectrometer, or an entire heat-treating laboratory, instead of buying one or all for its own laboratory. The chemical industry has long been a leader in research. J. V. Sherman, in *Barron's*, recently analyzed the 1950 research expenditures of eleven large chemical companies. Their average indicated research expenditure per research worker was $6983. For the four largest independent institutes, the corresponding average was $6150.

4. An objective approach is used in research at the institutes. Broad experience makes possible research which combines both factuality and imagination to the highest degrees. The tendency of many industries to build their new research laboratories at some distance from their plants seems to confirm the institutes' belief in the divorcement of research from the interruptions and distractions of plant trouble shooting. To the institutes, research is a full-time job pursued by specialists—their staff—and designed to be of maximum benefit at minimum cost to the sponsor.

5. Research at an institute may fill a temporary need. A petroleum refiner, for example, may need to expand his petrochemicals research for two years, no longer. This increment can be undertaken by an institute with its permanent staff without undue hardship. As another example, a petroleum refiner, not versed in paint technology, may authorize research on the utilization of his products and by-products in organic coatings. After two years, three years, five years, this new field may look so promising that a paint laboratory and one or more paint chemists may become a part of the

petroleum company's research department. If the outlook is unattractive, however, the project can be cancelled without prejudice, or its subject can be changed. This is another case of avoiding unsound investments in men and machinery, postponing the decision until near certainty can be counted on.

6. The research institute is independent, ethical, and unbiased. Industrial sponsors may place every confidence in it, certain that all desired secrecy will be maintained. Investigations take place there in a completely unprejudiced manner to yield the most accurate possible answers.

Making the most of these advantageous features, industry and the research institutes have come to the present with their heads and hands together, able to review a gratifying past, anticipating a challenging but even more rewarding future. The present covers a narrow band of time, extending into neither the future nor the past. It is subject to a sort of Heisenberg uncertainty principle. Upon considering the present we immediately relegate it to the past. Part of this dilemma results from the fact that statistics are not subject to instantaneous spontaneous generation.

PROBLEMS

What of the present, however, of institute research for industry? It is far from informative to say merely that it is active, it is growing, it covers essentially all fields of the sciences including economics. Has it no shortcomings? Most certainly it has, but surprisingly few that are detrimental to the welfare of sponsors. There is a public relations problem. If research institutes are nonprofit organizations, it is inappropriate to advertise their services. If they sincerely believe that they are an important aid to industry, their existence and mode of operation should be widely known. By "widely" is meant throughout the world, not by any means merely throughout North America. American industrial management prides itself on knowing sources of goods, services, and money, if they exist. How similarly important it is to know sources of the technical services and information which currently have such an important bearing on corporate health and even its life expectancy.

There is a problem of distributing the services of the institutes among sponsors of various sizes. Large industry is benefited and so is small industry, but are the projects properly distributed in number and size? The new projects at Battelle Institute during 1949 and 1950 were sponsored by companies of different total assets as

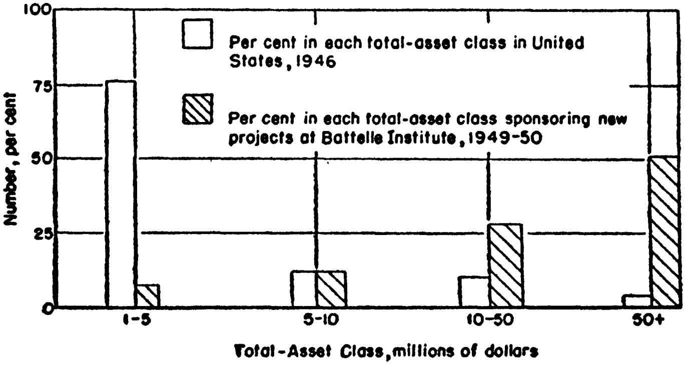

FIG. 2. United States manufacturers with total assets greater than $1,000,000.

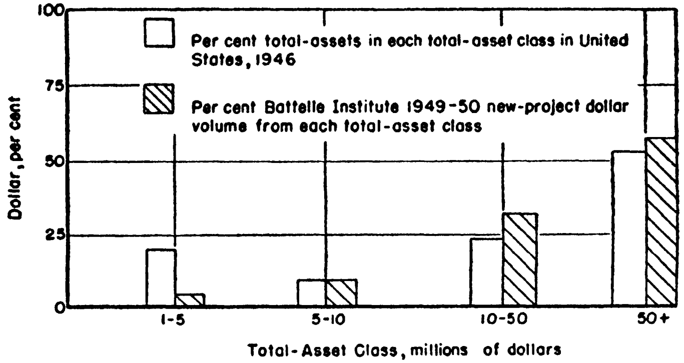

FIG. 3. United States manufacturers with total assets greater than $1,000,000.

shown in Figs. 2 and 3. In each case, a comparison is made with the nationwide distribution among these total-assets classes of manufacturers for 1946, the latest data available. Inspection will show that there is a considerable research potential among the firms having total assets between 1 and 5 million dollars. It is not hard to guess why this group has failed to grasp the opportunity to project itself into the technological future. Few of them being active in research, they do not actively seek help. The public relations problem again appears here. Some among these smaller companies are undoubtedly the victims of arrested financial development because they do not have a research viewpoint. Let it be clearly understood, however, that lack of money is not a deterrent to this group of potentially progressive manufacturers. The chemical industry survey published by *Barron's* showed an average investment of 2.7 per cent of gross sales by those eleven large chemical companies in research. A survey by the National Association of Manufacturers in 1947 gave corresponding figures of 1.6 per cent for all manufacturers having research programs and 0.64 per cent for those of the primary metal industries doing any research at all. Any research, if done properly, is better than none. Many among small industry can afford to invest a modest 1 per cent of gross sales in research. In fact, few can afford not to, with technological obsolescence the factor that it is today. A unit project in one of the independent, nonprofit research institutes should be available, then, to any company with annual gross sales of $2 million or more. In addition to that, 14.9 per cent of the new industrial volume of 1949–50 at Battelle was sponsored by groups of companies. This concept extends the availability of research to many more, including as an approximation units having annual gross sales of perhaps $200,000.

With the foregoing description of the institute's place in industrial research, the reasoning leading to the following conjectures on horizons in industrial science will become apparent.

It is obvious that anyone who has written what precedes this will be firmly convinced that the horizon will form an entirely imperceptible boundary between a rapidly expanding relationship between industry and the research institutes now and a continued tendency in that direction in the future. The institutes will become larger. There will be more of them. Industrial science will benefit accordingly and so will the public who is at once the consumer, the employee, the stockholder, the taxpayer, and the government.

NEED FOR TRAINED STAFF

If this is truly to be for the common good, progress must not be handicapped by shortages of trained manpower. We, the people, have been slow to provide the facilities necessary for the more rapid training of doctors in our medical schools. This is now being corrected, but the same must be done for future physicists, chemists, engineers, biologists, and others who will be essential to our research effort beyond the horizon of time. Industries will do even more in this direction than they are doing now. There will be more fellowships and higher stipends. There will be, or certainly should be, more endowed chairs to recognize outstanding professors and to encourage them to continue their output of creative graduates. Too often the route to an improved economy for a professor leads to an administrative job which insulates him from students and puts an end to his teaching and research. Industry will carry on the start it has made in fanning the spark of interest in science shown by high-school students and even younger ones. It is to be hoped that the attention given the promising football players, age 12, may be at least equaled among their science-bent colleagues.

Even the college curriculum will evolve at the behest of its products' employers-to-be. Industry is becoming increasingly impressed with its needs not only for creative and productive thinkers and doers but also for men who can write and talk lucidly, who can deal with others on a psychologically sound basis, and who have a feeling for economics. All of this will go far to improve the quality of the universities' scientific graduates while increasing their quantity as well. To assure a continuing supply of first-rate research scientists is a duty which, although primarily a task of the universities, is a responsibility which industrial science will not dodge.

NEED FOR FUNDAMENTAL RESEARCH

Perhaps as a part of its increased participation in training scientists, industrial science will lend added moral and financial support to fundamental research. During twelve years of war and warlike times, there has been a strong tendency to leave such basic pursuits to government sponsorship. We are even now observing the effects of budget and policy uncertainties on two widely different research programs of the federal government. Such conditions are fatal to good research. American industrial science has the ability and the resources to minimize similar wastes of money and scarce manpower.

It has been said since the war that our reserves of basic scientific knowledge have been depleted to such an extent that applied research may soon be seriously handicapped. A resurgence of such effort is called for. It is suggested here, however, that the needs of industrial science which correspond to the needs of the world's population be considered in planning the fundamental research of the future. That of the past has contributed much to man's needs and comforts. A substantial part of it, however, has been of no demonstrable use in the foreseeable future. With constantly increasing scarcities of technical manpower, it may well be asked whether the research merely to develop new knowledge, completely regardless of potential applicability, is in the best interests of all, particularly of the investigator himself.

CLASSIFICATION AND COMMUNICATION

How many pages of reports are required to record the results of the $1000 million worth of industrial research in 1950? How many to record the new results on vinyl polymers in that year? Who can keep completely abreast of a field like the latter? Obviously no one can keep informed on more than a relatively narrow field of science. The production of such an enormous volume of information underlines the need to improve methods of classifying and communicating intelligence. This is an activity which is on the horizon of industrial science. A start has been made. Much more will be done in the future. It might be ventured, at the risk of being quite wrong, that the alchemist of old knew about as much about the alchemy of his day as the modern chemist knows about modern chemistry. Although improvements in communications methods have enabled one to absorb much more, the volume of chemical research output must have increased somewhat proportionately. The difference is that the chemist of today knows where to find the information he needs when he wants it.

NEW PROCESSES AND MATERIALS

Beyond the horizon of industrial science lies an increasing number of tailor-made materials. There was a time when gasoline was a fraction distilled from crude oil. It is a very different material today.

With its content of alkylate, isomate, hydroformed product, polymer gasoline, catalytically cracked product, reformed naphtha, antiknock agent, and gum inhibitor, it bears little resemblance to its original self. Modern engines have demanded such a fuel, however, and industrial science has produced it. Many of our present-day scientific wonders may be attributed not so much to contemporary ingenuity as to newly available materials which make them possible.

Polyethylene, the nation's most promising plastic, depends much for its availability at moderate prices on high-temperature techniques in the production of the raw material in quantity and on high-pressure techniques for its manufacture. Special alloys are important in both stages.

Currently in the pilot-plant stage is a process for the production of nitric acid solely from air and water. If final economics are attractive, this could have a profound effect on important branches of industrial science such as the fertilizer industry, but it would not have been possible without the development of a pure magnesia refractory capable of resisting the high temperatures involved.

One might think that there is nothing new in the periodic chart except among the transuranium elements. It is true that titanium, as an element, is not new but pure, ductile titanium in quantity is new. Its promise for the future is great. Judging by the nature of the research leading to the processes for its manufacture, industrial science saw the need, designed the product, and made it.

So it will be, to a greater and greater extent in the future. New and improved fibers will be designed from the molecule up. Better alloys will appear constantly. Temporary shortages or unusually high prices may mean permanent abandonment through the ability of industrial science to devise substitutes in the best sense of the word. Copper, at the present time, is yielding to aluminum. Much synthetic rubber is here to stay.

INTERNATIONAL TECHNICAL COOPERATION

The most important prospect on the horizon of industrial science, however, is that of technical cooperation on an international basis. Whole-hearted cooperation and confidence can raise industrial research to a plane of quality and output still unrealized. The resulting exchanges of ideas, research methods, and results should go far to improve the lot of mankind. Highly developed technology makes possible an active industrial climate. Accordingly, prosperous industry can pay higher wages to its more creative employees and can hire still more to expand output. It is the nation with the highly productive industries which can supply both the necessary and the luxury wants of its people, and what makes the nation if it is not the people themselves.

The research institutes, aware as they are of the needs of industrial science, are even now establishing offices, laboratories, and staffs in Free Europe. It is their most sincere hope and expectation that they may play an important part in the growth and perfection of industrial science among America's friends throughout the world.

By staffing their laboratories abroad with the best of research scientists working in their own countries, the institutes can provide a high-caliber combination of native scientists with liaison and general supervision from their home organizations. With such facilities, European industry, for example, would have ready access to American methods and approaches in both research and production. At the same time, however, actual project work would be done by the sponsors' fellow countrymen who are completely conversant with their nation as well as its special problems and economics.

One very substantial by-product of this added research activity would be the resulting increase in the number of graduates available to industrial science in the countries involved. In the United States, the research institutes have encouraged education in the technical fields. This should be no less true in Europe, particularly since one institute is even now establishing university fellowships there for outstanding students who will remain after graduation to work for the greater prosperity of their native land.

But what will the research institutes get out of this expansion to Europe and elsewhere? Not money, certainly, for essentially all of them are nonprofit organizations. Satisfaction? Yes, very much. There is not a great deal of difference between the satisfaction derived from the successful development of an appropriate plasticizer for a manufacturer of plastics products and being leaders on the road to the potentially enormous titanium industry. Each gives a sense of accomplishment and service. How much more satisfying, however, is the prospect of aiding international industrial science in its journeys to and beyond its horizons and in so doing creating new ones. How satisfying is the possibility of contributing to improvements in crops, nutrition, and utilization in an agricultural nation, to raw materials, and production methods in an industrial nation. Still more attractive is the anticipation of bringing together two such economies to their mutual advantages.

The horizons of industrial science make clear that its role is Promethean but, like a mountain silhouetted against a clear evening sky, the present, too, calls for heroic efforts.

As the here and now furnishes our immediate challenge, the horizon—our wider future—provides the incentive to act for the welfare of posterity. Our forebears knew vaccination, mild steel, and nourishing food, but beyond their horizon lay antibiotics, stainless alloys, and the essential vitamins and food minerals. Can we, through industrial science, do as much for the world's generations to come? We can and most certainly will do this much and more.

Horizons in Industrial Science from the Viewpoint of Government

ALAN T. WATERMAN
Director, National Science Foundation, Washington, D. C.

The inauguration of a section on industrial science at this, the 118th meeting of the American Association for the Advancement of Science, is a noteworthy occasion. We may well ask ourselves why this kind of recognition of the important place occupied by industrial science has lagged so far behind the fact. For at least half of the century during which the American Association for the Advancement of Science has existed as an organization and institution, industrial science has played a significant part in the growth and development of our national economy. It would be difficult to dissociate the economic and social history of the last fifty years from the rise of such great research laboratories as those of DuPont, Bell Telephone, and General Electric, to name but a few.

My topic calls for a discussion of horizons in industrial science as seen from the viewpoint of government. If we think for a moment of the government in its broadest interpretation as being all of us as citizens, then horizons in industrial science hold for the government as for everyone else the promise of a brighter, more effective way of life.

I should like to consider this aspect of the matter for a moment and then return to the interrelationships of government and industry with respect not only to industrial science but also to basic research.

Many of us have in our lifetimes witnessed the growth of what is virtually a new world. This world has been made possible by the practical applications of science to the needs of everyday living. The inventive skill that is so characteristically a Yankee quality has taken the abstract concepts of the basic scientist and scholar and applied them to problems of transportation, communication, agriculture, health, and welfare. When we contemplate the future in terms of the possibilities that are held out to us, we realize that the potentialities for continuing advances along these lines are even greater than the achievements we have realized thus far.

EFFECTS OF THE DEFENSE EFFORT

In the five years following World War II we have not been at peace, althought at first we thought we were, and the normal course of invention and production has been increasingly interrupted in many ways by the exigencies of the defense program. The volume of military research and development, for example, has more than doubled since the close of the war and is requiring more and more of the scientific resources of the country. In similar fashion, defense production has necessarily diverted many skills and scarce materials that might otherwise have been devoted to the development of ways and means for improving our national welfare and health.

In spite of the burden of adequate arms preparedness which we have imposed upon ourselves, we find that technological progress for civilian and peacetime purposes has continued to make impressive progress. The most cursory review of developments during the past year produces so many items of interest that it is possible in a brief space of time to mention only the smallest number of them.

The atomic energy program, which is proceeding on such an enormous scale to provide us with the necessary weapons, is at the same time producing as a by-product medical and biological discoveries the significance of which may far outlive the atom bomb. For example, the Victoria Hospital in London, Ontario, recently dedicated an altogether different type of "atom bomb." This is the cobalt "bomb" for cancer research, constructed at a cost of $50,000. The *New York Times* reports that the bomb represents a rough equivalent of 50 million dollars worth of radioactive radium, a quantity which is in excess of all the radium available on earth. This bomb is also more powerful than a $150,000 x-ray machine. So although no claims are made as yet for the efficacy of the cobalt bomb as a weapon against cancer, it at least makes possible an important radioactive instrument that can be provided at much lower cost than the equivalent radiation by radium or x-ray.

SCIENTIFIC AND TECHNOLOGICAL ADVANCES

During 1951 another milestone in communications was passed when the American Telephone and Telegraph Company instituted for the first time the "dial-it-yourself" long-distance telephone service on a coast-to-coast basis. The most conservative estimates indicate that it is possible for a citizen on one coast to put through a call to the other coast in something less than half a minute.

In the field of transportation, aviation experts predict inauguration of commercial jet-airliner operations which will make possible such extraordinary service as five-hour crossings of the Atlantic. Meanwhile, the use of nuclear energy for propulsion moves closer to being a reality. Although the Defense Department has been conservative in predicting the probable dates by which atomic-powered craft will go into operation, recent announcements by both the Navy and the Air Force appear to bring the date nearer. The Navy has not only indicated that an atomic-powered submarine may be ready by 1954 but has already chosen to call it the *Nautilus*. Earlier this fall (1951) the Chairman of the Atomic Energy Commission ventured the cautious prediction that within the next decade we may see a plane which is powered by a nuclear reactor. Only two weeks ago the Air Force announced the letting of a second contract for the construction of such a power plant.

Nor must it be assumed that all the spectacular hints of things to come are to be found in the physical sciences. Some of the basic research going on today in the biological sciences has profound implications for our economic life in such widely diversified areas as power and agriculture. Biology holds out the promise of new solutions to age-old problems. The potentialities of atomic energy for power purposes have been widely publicized and discussed, but the potentialities of solar energy are much less widely understood and appreciated. One important manifestation of solar energy is in the process by which plants create living matter by combining chemical substances with radiant energy. But it has been pointed out that under the most favorable conditions not more than 2 per cent of the light energy which falls on a crop of the ground is harvested as plant material. Recent research, however, indicates that under ideal laboratory growing conditions as much as 20 per cent of the light energy can be so transformed into chemical potential energy. It is not difficult to visualize the far-reaching effects upon agriculture and the world's food supply that even a doubling of the per cent of light energy utilized by the plants would mean. The cultivation of algae in vastly increased quantities as the source of food, fats, and drying oils offers a profitable field of research in this general area.

DIVISION OF LABOR IN RESEARCH

The continuing process by which science and technology join forces to satisfy and add to our material comfort represents the happy fusion of a number of kinds of research efforts. For our own convenience we have fallen into the habit of calling these different kinds of research by such descriptive names as basic research, applied research, development and engineering. A rather convenient division of labor has also evolved through which the universities and other academic institutions have carried the responsibility for basic research, while business and industry have found it profitable to foster mainly the applied research and engineering phases. The government's role has been that of both sponsor and participant. Specific need has tended to dictate the direction of these various efforts, and until recently few problems have arisen in connection with this rather logical division of labor.

The growth of industrial research activities during the last fifty years has been a development which the government has every reason to view with favor. Through the creation of rapid means of transportation and communication and through the techniques and processes of low-cost mass production of essential commodities our standard of living has constantly risen until, from our point of view at least, it leads the world. In times of war the industrial production capacity of the United States has proved to be a decisive factor. More recently, the government looks primarily to industry to develop and produce the new weapons, instruments, and techniques that may provide the crucial advantage over our enemies. World War II demonstrated conclusively that science must occupy an important place in our defense councils.

To the extent that the applied research carried on by industry meets national needs, the government prefers to avail itself of the results achieved by industry rather than to duplicate its efforts. The research carried on by the fuel industry, for example, has saved the government millions of dollars in taxpayers' money.

GOVERNMENT RESEARCH LABORATORIES

On the other hand, the government has certain types of research needs of a continuing nature or that are not otherwise being met, and to meet these needs the government has established its own laboratories. The National Advisory Committee for Aeronautics performs aeronáutical research of great importance not only to military aviation, but also to commercial aviation. The laboratories of the Department of Agriculture, the National Institutes of Health, the Bureau of Mines, Bureau of Fisheries, the National Bureau of Standards, the Geological Survey, the Coast and Geodetic Survey are examples of government research activities which contribute to the national welfare in an overall way. It would be difficult, as well as impractical, for private organizations to try to meet the need for the kinds of data supplied by such laboratories as these.

In recent years the nature and cost of modern weapons has made it necessary for the government to assume the financial burden of certain laboratory and testing facilities owned by the government and operated by contractors. Atomic weapons, quite apart from their special security considerations, are an outstanding example in this category as are also guided missiles and rockets.

Government-sponsored research, as well as research performed in government laboratories, in addition to meeting the immediate needs of the government, often produces important results for industry as well. Navy-sponsored research on the diesel engine and on high-pressure steam, for example, paved the way for important industrial applications. Currently, the research on titanium which the government has supported appears to be approaching the fruitful stage. Several large industrial companies have launched programs of their own in this field based on the extraction process developed by the Bureau of Mines. Dr. W. R. Johnson, Supervisor of Research Information Service of the Illinois Research Foundation of the Illinois Institute of Technology, has commented editorially on this subject in the December issue of the Department of Commerce Bibliography of Technical Reports:

> In the past the history of the large scale development of a metal has begun with processes for relatively inexpensive extraction, followed by rapidly increasing applications, and then laboratory work on alloying and the fundamental metallurgy of the metal. However, because of the attractive physical properties of titanium and its ultimate potential demand, the government has been able to reverse this procedure. Before the extraction metallurgy is fully worked out and while ultimate applications exist only on paper, a great amount of fundamental work on titanium and its alloys is being sponsored by the U.S. Government. When industry begins to produce low cost titanium metal, we will be able to use it with an extensive technical background already available; government sponsored research is advancing the technology of this metal many years.

APPLIED RESEARCH VERSUS BASIC RESEARCH

The interrelationships of government and industry with respect to applied research would thus appear to be on a mutually satisfactory basis. As I have thought about the subject of today's discussion, however, it has seemed to me that both government and industry have a special obligation toward the other important phase of the research effort, namely basic research. Both government and industry depend upon basic research and education in the sciences and have a mutual responsibility for insuring its support at adequate levels.

If it were possible for nature to take its course in these matters, universities would probably not require assistance in order to discharge what is a traditional and cherished responsibility, the pursuit of new scientific knowledge. As applied research increases in volume, however, it tends more and more to drive out basic research. Probably the single most important contributing factor, and one which is obviously beyond our control, is the necessity for a large-scale military research and development effort. During World War II and since the war the Department of Defense has drawn heavily upon the universities for the solution of important problems in applied research engineering. The drain upon manpower and facilities is having its effect upon the normal basic research activity of these institutions.

In addition to heavy teaching schedules and the burden of administrative duties which normally plague the life of the university investigator, there is now, in many cases, the call upon his time for assistance in the solution of problems in applied research. These difficulties, perplexing as they may be, are nevertheless specific and capable of solution. A greater threat to the continued existence of basic research is subtler and less susceptible of definition. Applied research is not only, in many instances, more attractive financially than academic pursuits, but it also carries with it an excitement and urgency that is likely to have more appeal, particularly for young investigators, than the uncertainties of long-range studies that are not visibly related to the exigencies of the moment. As long as a scientific manpower shortage continues, basic research must compete for the senior scientists of the future with the greater financial rewards and stimulus of applied research.

Science depends for its own self-perpetuation on the inspirational and stimulating leadership of capable science teachers. They, more than any other group, hand down the flame of pure scholarship to the younger generation, but they, too, are in short supply, and many demands encroach upon the time which they are able to give to education in the methods of research.

THE NATIONAL SCIENCE FOUNDATION

The people of the United States have accepted a public responsibility in this matter through the establishment by Congress in 1950 of the National Science Foundation. The Foundation has been specifically directed:

> to develop and encourage the pursuit of a national policy for the promotion of basic research and education in the sciences;
>
> to initiate and support basic scientific research in the mathematical, physical, medical, biological, engineering, and other sciences;
>
> to award. . .scholarships and graduate fellowships in the mathematical, physical, medical, biological, engineering, and other sciences. . . .

However, the funds which have been appropriated for this purpose are limited—$3,500,000 for fiscal year 1952. It is our intention to devote these funds to the support of basic research, largely through the award of grants, and to education in the sciences through the award of fellowships. The fellowship program has already been announced and will get under way in the academic year 1952–53 with the awarding of four hundred graduate fellowships in the natural sciences. Proposals for research projects are being received in increasing numbers, and the award of grants will probably begin early in 1952.

INDUSTRIAL INTEREST IN SCIENCES

We hope that industry will find it possible to augment these efforts with substantial support of similar kind. I am aware, of course, that a number of industrial groups are already awarding fellowships in the sciences, and it is to be hoped that other companies will swell the number. The United States Office of Education has recently completed a survey of scholarships and fellowships available from all sources in the United States, and it has concluded that, generous though these are, they are not enough. The Commissioner of Education, Earl J. McGrath, commented: "Many hundreds of thousands of high school graduates just as able and ambitious as those in college each year failed to begin or to complete their higher education principally for financial reasons."

Nor are our leading businessmen unmindful of the problem. Alfred P. Sloan, Jr., Chairman of the Board, General Motors Corporation, writing in an article which appeared in *Collier's* last June, made a strong plea for corporate assistance for schools and colleges. Mr. Sloan said:

> Why should not corporations do their proper part in furnishing financial support for our colleges, universities and technological institutions?
>
> And why should this not be done in an organized, rather than haphazard, fashion?
>
> Moreover, why should not such support be recognized as a proper use of the funds of corporate enterprise, comparable to their use for its other activities?
>
> We must remember that to a major extent our institutions of higher learning provide the basic knowledge which productive enterprise applies to its material advantage, and, in so doing, supports and advances our standard of living.

Even more recently Irving Olds, Chairman of United States Steel, made a similar plea in an address at Yale University. Mr. Olds said:

> Every American business has a direct obligation to support the free, independent, privately endowed colleges and universities of this country to the limit of its financial ability and legal authority. And unless it recognizes and meets this obligation, I do not believe it is properly protecting the long-range interests of its stockholders, its employees, and its customers.
>
> Every well-managed corporation, of course, must preserve, improve, and develop the major sources of its raw materials; but if it is necessary for us to spend millions of dollars to beneficiate the ore which goes into our blast furnaces and to process the coal which goes into our coke ovens—then why is it not equally our business to develop and improve the quality of the greatest natural resources of all—the human mind?

Naturally, not all of us who are thinking and speaking along these lines are in complete agreement as to how these things should be done, nor even as to how much of the burden should be carried by individuals and private organizations and how much should be the responsibility of the government. The important thing, however, is that we are in agreement that the need exists and that the government and industry each have responsibility toward basic research and education in the sciences. There is little likelihood in the immediate future that the need will be oversubscribed.

In concluding, I might say that horizons in industrial research will continue to look bright to the government as long as we are assured of a continued flow of new knowledge and new ideas stemming out of basic research and as long as we are sure of a continuing flow of our trained young investigators who are talented, imaginative, and skilled in the ways of research, for these are the indispensable prerequisites to the security and welfare of the country as a whole.

PUBLIC ASPECTS OF INDUSTRIAL SCIENCE

The Contributions of Industry to Scientific Education

C. L. EMERSON

Vice President, Georgia Institute of Technology, Atlanta, Georgia

THE rare metal germanium has attracted considerable notice in recent years because of its unusual properties. In electronics, for example, ordinary transistors may be replaced by a germanium device taking up a fraction of the space and operating with negligible heat. The use of germanium would have been extended with amazing rapidity were it not for its scarcity. There seems to be only one ore-bearing vein in the United States in which a reasonable percentage of germanium is found.

Perhaps there is in the foregoing somewhat of a parallel bearing on those of our colleges and universities that teach science and engineering. They are indubitably the sole source of new research talent for industry and the principal producer of technical managerial talent. It is not anticipated that this fact will create as much interest as the search for new sources of germanium, but it may be worth a passing thought.

In this brief paper, the discussion of scientific education is limited principally to the field of physical sciences and engineering. Including the sciences of life and medicine would expand the topic unduly. As a further definition of terms, industry will be taken to embrace manufacturing, commerce, and trade, conducted generally under the corporate form.

INDUSTRY'S INTEREST IN EDUCATION

Industry has traditionally interested itself to some extent in higher education, but its interest has been increasing rapidly in recent years. An example of this can be cited from the experience of one of our leading engineering colleges, which states that from 1928 to 1948 corporate support accounted for 7 per cent of all gifts. In 1947, this figure had risen to 12½ per cent, and in 1948, it represented 26 per cent of all gifts. Money is a tangible expression of interest.

It is a fact, sometimes not fully realized, that industry by virtue of its existence, growth, and tremendous productivity has made the entire economic fabric of this country strong. This strength has provided most of the tax funds which have made public education possible, and from it has come also most of the resources from which philanthropic individuals assisted the privately endowed institutions of higher learning.

Let us consider today's situation and the more specific contributions which industry is making to scientific education. A modest amount of library research has developed the fact that there are over forty separate and distinct methods by which such aid is being given. Manifestly, the time limitation does not permit a complete discussion of each of these. In an effort at condensation, they are grouped into seven general categories, so that the genus may be covered, though some of the species may be omitted.

CORPORATION SCHOLARSHIPS AND FELLOWSHIPS

First should be mentioned the help given to students, the traditional form of which is the undergraduate scholarship where all or part of a young man's college expenses are borne by the donor. In a democracy such as ours, the doors of opportunity should be held open to those who have the mental capacity and the determination to learn, but whose families may lack financial ability.

Many of our most successful business and professional men of today were boys of serious purpose, who were aided in this way to obtain a higher education, and who, perhaps, took better advantage of their opportunities than those to whom it came as an unappreciated gift.

One of the finest forms of cultivating labor-management relations is the award of such scholarships to the children of the employees of the corporation, for many in the ranks of labor have great but unrealized aspirations for their sons.

Graduate fellowships take up where scholarships end. Since college graduates have usually attained the age of twenty-two or twenty-three, they are married or thinking seriously of marriage, so that an unaided program of continued study of from one to three years seems a most formidable undertaking. Fellowships, while fewer in number than scholarships, seem markedly on the increase.

One area of increase is in that of the research fellowship. Usually the grantor corporations show a most enlightened policy by not requiring that they be given any direct benefits arising from the research or that the recipient enter their employ upon the completion of his education. Recently a few companies have arranged for such research fellows to do their thesis work within the industry itself. While this development entails certain additional trouble in planning, it proves rewarding to both and frequently results in the plant obtaining a desirable employee.

ASSISTANCE TO PROFESSORS

Our second heading should deal with aid to members of faculties. This topic covers a wide spectrum, but probably the most practical item is the employment by industry of the professor for a summer term, a sabbatical year, or even a longer period based on leave of absence. The professor's experience greatly improves the worth of the classroom instruction which he gives upon his return to the ivory towers.

Such opportunities are limited, however, as compared with the supply of a great mass of instructional aids in the form of books, pamphlets, publications, and films of varying merit. One large corporation provides 28 different texts (which are excellent) in the field of communications alone.

The great hope of the institutions is for endowed chairs where a fixed income permits the addition to the faculties of outstanding scholars whose services could not be obtained through the slender resources of the college. Furthermore, the older and abler professors look forward hopefully to employment as consultants in industries allied to their fields of specialization. There are some Elysian fields where more is returned for part-time consultation than the annual salary paid from the school budget.

COOPERATIVE EDUCATION

There may not be a complete justification for a third category where a young man is both a worker in industry and a student in college as in the so-called cooperative form of education. This may be considered more of a benefit rendered by the schools to the industry, than vice versa, but on the whole, it is a safe conclusion that the student gains more than the employer in most cases today.

In many forms of cooperative undergraduate education, two boys operate as a team. While one is on the working job in the plant, the other is attending classes, perhaps a thousand miles away. They then exchange places, usually after an interval of three months. Normally, five years are required to complete the regular four-year course. Vacation periods are limited, and the opportunity to engage in extracurricular activities is reduced. However, the value of hard work and the full recognition of the necessity for learning are more than adequate compensations to the student.

This combination of work and education takes several forms, even at the graduate level. At concentrated industrial areas such as New York, Chicago, and Pittsburgh, for instance, there are outstanding graduate schools operating in the evening for the benefit of young men who are employed full time during the eight-hour day. Many well-qualified men from the manufacturing plants of the area give sacrificially of their time and efforts as part-time faculty members. It is hoped that as industry becomes more evenly spread over the United States, many other such schools may be established.

Certain graduate schools are also financed and operated by a particular segment of industry, as for instance, the Institute of Paper Chemistry, where selected college graduates are able to obtain advanced degrees and also where valuable research is done for the paper industry as a whole. Aside from the close focus within which such institutes operate, they provide an excellent means to carry education to higher levels.

A few of our more advanced technological colleges operate what are called "practice schools" for graduate students. Here a young man seeking his Master's degree spends full time in manufacturing plants, but as a student, not as an operative. The arrangement usually includes three or four industries of different types, such as a steel mill, a paper mill, a textile mill, and a chemical plant. At each are stationed one or more full-time faculty members who must be not only fully conversant with their subjects, but must also be sufficiently diplomatic to obtain hearty cooperation from the plant superintendents. The students go from plant to plant, spending three or four months in each, making tests, preparing flow sheets, operating quality control, and engaging in other activities which give them not only a theoretical but also a highly practical knowledge of the processes and operations. This type of graduate work should be adopted by more universities and probably would be except for the high cost.

CONTRIBUTIONS IN KIND

It has been common practice for many years for corporations to provide equipment for college shops, laboratories, and research departments. Equipment which may be considered surplus or even almost obsolete by industry is valuable to colleges, particularly if it comes as a gift. Rare research equipment is also given occasionally.

Perhaps in money value, the greatest contribution has been made in the form of educational discounts from standard prices on machinery or equipment sold to the schools. This has become such an accustomed procedure that we lose sight of the fact that millions of dollars have been saved by college purchasing agents through this means.

SHORT COURSES, CONFERENCES, SYMPOSIA

Our fifth category has to do with the help given to extension divisions in the operation of short courses, conferences, and symposia.

Much of the value of these gatherings would be lost if those attending did not receive papers and lectures from outstanding executives and scientists who come to them from industry without any cost for travel expense, or honorarium. This opportunity for the local professors to mingle with leaders from government and other schools, as well as from industry, is a source of stimulation to the faculties. Business and manufacturing concerns are now beginning to operate seminars, thus reversing the flow of travel by bringing in college people, particularly research people, to speak on their specialties before groups of industrialists. Here the receipt of travel expense is almost mandatory and that of an honorarium is exceedingly welcome.

INDUSTRY-SPONSORED RESEARCH

Engineering and scientific schools are increasingly devoting more of their attention to research. Perhaps unfortunately, a considerable part of this stimulation has come from the federal government in the field of weapon development. Industry is realizing that it should, to an increasing extent, sponsor research projects in the colleges. The larger industries have well-established research departments of their own, but there are many side lines of investigation which they do not have time to pursue and which could be sent to those colleges where professors of real talent are available. Particularly in the realm of fundamental or basic research such sponsorships may be established with great benefits and at little cost. Many smaller industries are in position to do more research, particularly fundamental research, through the medium of their trade associations or foundations acting for them jointly.

Some industries are limiting their help to the grant-in-aid, where only a portion of the cost of the work is borne by them, instead of by direct sponsorship, where the full direct cost plus an allowance for burden or overhead is paid. This is a short-sighted policy, since it limits acceptance to comparatively wealthy institutions who can afford to absorb part of the cost in their academic budgets. It is desirable to develop new sources of research talent and to provide the smaller scientific and engineering schools with the beneficial results of an active research program.

Our last division is the one which comes first in the mind and heart of all college presidents—the direct gift or grant of money, preferably undesignated. It is perhaps unnecessary to dwell on this here, except to say that the tax policies of our country are eliminating the individual giver, and the only substitute for him is the corporation, or the ever generous federal government. This is perhaps the last generation which can accumulate large personal fortunes, so perhaps this may be also the last generation of college presidents whose grief at the passing of some dear old alumnus may still be slightly assuaged by the knowledge that the will provides a bequest for the beloved institution.

The overall study of these seven forms which the contributions of industry to scientific education take indicates two general trends. One of them is that education is endeavoring to lift its level by increasing the volume and improving the quality of graduate instruction. In this effort industry is assisting to the end that engineering education may become more scientific and scientific education more practical. The other trend is that the two are drawing continually closer together by the exchange of ideas and men. It would appear that both trends will accelerate.

FINANCIAL DILEMMA OF THE COLLEGES

The colleges are today facing a very difficult situation, particularly in regard to their financies. The dollar in the last decade has shrunk to about half its 1940 size, so that everything which the college buys, from chalk to cyclotrons, has almost doubled in cost. At the same time policies of the federal government have reduced interest rates on securities or other investments held in their endowment.

Figures have recently been published which show that in the case of college endowments representing about half the total for all colleges, the actual number of dollars returned was about half what it would have been twenty years ago. When this decrease in the number of dollars is coupled with the shrinkage in purchasing power of each, we find that the college controller gets about 25 per cent of what he obtained from the same endowment in happier years.

In the meantime, the demands upon the schools have increased both in variety and scope. As one instance, engineering schools are being asked to set up and operate technical institutes for the noncommissioned officers (i.e., foremen) of industry.

As a result of these and other deleterious influences, the colleges are living on very lean rations. Of the approximately nine hundred privately controlled institutions, about half are operating in the red and two hundred of them are skirting the brink of bankruptcy. It is not a pretty picture.

Even tax-supported colleges in many areas are supported in name only. Federal taxes have become so high that the cities or states are having great difficulty increasing their own tax take. They can only resort to higher sales taxes which add fuel to the flames of inflation. Many land grant colleges are pinching pennies almost as energetically as the private or church-related universities.

This financial depression in colleges is not a passing phenomenon. Consequently college professors, being intelligent men, are looking about and are being drawn by adequate compensation, as contrasted with starvation salaries, into government or industrial positions which are readily available to engineers and scientists.

It is rather depressing to see a college graduate, perhaps with a Master's degree, being employed at once by industry at a higher salary than that received by a professor who taught him and who often has had twenty or more years of experience. If the faculty fabric is once seriously deteriorated it cannot be woven back again overnight. Faculty members may have a scale of values higher than money return, but nevertheless, their wives must wear clothes, and their children must be fed and educated.

In their extremity, where will the colleges turn for help? They should not and probably cannot put any greater part of the cost on the students by raising tuition again. In fact, such raises have now almost reached the point of diminishing returns.

NEED FOR INDUSTRIAL SUPPORT

It would seem that they must turn to the great and strong corporations for their support, and it should not be too difficult for industry to help them. Research sponsorship can be charged against operating expense like any other cost of doing business. Direct gifts or unspecified grants can be made from the allowable deduction of 5 per cent to corporations for gifts to wholly scientific, educational, religious, or charitable organizations. In the last year of record, 1948, the average deductions made for all such purposes by all corporations was only 0.7 per cent, instead of 5 per cent, so there remains plenty of leeway for giving. If the full 5 per cent had been utilized last year by all industry, it would have amounted to 2.2 billion dollars.

Some corporations have been hesitant about gifts to colleges, fearing that such gifts were beyond charter powers and subject to challenge by stockholders. Few such suits have been instituted, and the courts show an increasingly unfriendly attitude toward them. Certainly, if a gift is made to a college educating and preparing the human raw material for development by the industry into future management talent, there should be no grounds for complaint, any more than about the money spent to discover and develop a body of ore, germanium, for instance. Even where the direct connection is tenuous, we find that twenty-two states have already passed laws clarifying the rights of corporations chartered by them to give to education. The colleges need more help from industry. All but a few of them face a bleak outlook if support is not forthcoming from this source.

IMPORTANCE OF COLLEGES

Perhaps it will sound somewhat surprising to say that industry has almost equal need of the colleges. What determines the relative success of a certain corporation? Why does it prosper more than another in the same line of business? In the United States today all manufacturers have access to the same raw materials; they can purchase similar machinery; they are able, because of its mobility, to employ a similar working force; they can sell their products in the same great market.

A great industrialist has said that relative success is dependent on two things: first, superior management; second, research. Now the colleges are becoming the sole source of research talent, and the principal source from which the technical human raw material is obtained by the industries. This raw material is then further screened and educated for promotion to positions of managerial responsibility. As industry becomes more scientific, a still larger percentage of this raw material for management will come from the engineering and scientific schools.

At this time the source is drying up. There is presently a national shortage of sixty thousand engineers. It is estimated that industry could normally absorb annually about thirty thousand, if no shortage existed. Contrasted with this, we will have this year about twenty-five thousand graduates; but according to existing policies of selective service, about half of these will go into the armed forces. The future holds no hope since, owing to the decreased birth rate in the thirties and other causes, it is estimated that by 1955 there will be only sixteen thousand graduates. If the armed services still take half, the situation of industry will be deplorable indeed. The shortage of scientists is still more acute, and physicists of ability and experience are almost unobtainable.

BASIC RESEARCH

In the area of fundamental research, the United States has never been a leader. In the past we depended upon Europe for our basic science, and we, more commercially minded, led in development. In the last fifty years of Nobel awards in physics, chemistry, and medicine, only twenty have come to the United States, while Europe has received one hundred and nineteen. Thirty-six of these went to Germany alone. Of the basic scientific advances during the last war, penicillin and radar came from England, blood banks from the Soviet Union, and atomic fission from Germany.

Perhaps at no time in history has the gap between the level of basic scientific knowledge and the practical application of it been smaller. Someone has likened this situation to the installation of a battery of powerful pumps which have drawn upon the underground water-bearing stratum until the water table has dropped below the reach of the pumps. Thus development has drawn down our reservoir of basic science. We must replenish the reservoir. This will be done. It is generally agreed that the best place to propagate fundamental research is in the colleges where the climate is suitable to scientific growth and the iron pressure of too little time does not operate as it does in industry. Industry does some basic research in its own right, but such research is carried on in a continuous conflict with the commercial pressure for results and profits.

SPONSORING RESEARCH

The colleges will certainly do fundamental research. The question is, how extensively, and under what sponsorship. The National Science Foundation is set up to nurture it, this year with only a pittance, but you will recall that Dr. Vannevar Bush in his original report said that 200 million could be spent annually to good effect. Eventually government will discover how vital this operation is, both to our security and our prosperity, and will finance it. It is to be hoped that industry will not abandon the sponsorship of basic research entirely to government. Probably the most nearly ideal situation from all standpoints would be an equal participation by both. For this purpose government should establish for industry a special tax incentive not only by allowing research as a charge against operating expense, but also by using it in some form as a yardstick to determine a further abatement of the federal income tax. The administration of the allocation and the supervision of such basic research in colleges can be done much more effectively by industry than by government.

While industry has done many things for education, it has done only a small part of what it should do, not primarily as a matter of public relations, nor as an evidence of social consciousness, but as a matter of intelligent and long-range selfishness.

Since it is almost inevitable that this partnership will become much closer than at present, we can anticipate that the relationship will make some changes in the college pattern. We would hope to see the educators come out of their ivy-covered offices and open all the doors so that the keen winds of industry can blow through and carry away the last remnants of pretense, hypocrisy, slothfulness, and false pride which may remain from a more monastic day.

It is a truism that no college is greater than its faculty. Splendid buildings, laboratories, and equipment are only brickwork and plumbing without the trained, creative minds, and the indomitable spirits of men. While this is a truism, people do not act upon it. The time may arrive when industry will canvass its own ranks to discover men who are scholarly in their outlook and who would be happier on a faculty than in the hurly-burly of production. There are many such men who would return to college as teachers if industry would provide for them a pension sufficient to prevent a decrease in their earning power. Whatever is necessary can and should be done by industry to bring many of our engineering and scientific schools, widely scattered over the United States, up to the level of the best we now have. This geographical extension is necessary because of the serious manpower shortage which now exists, and since it would be undesirable to increase our relatively few top-flight schools to gargantuan proportions.

Basic research should be encouraged and fostered by industry far beyond any of the ultraconservative suggestions so far made. The college should be forced to accept a large payment for overhead in addition to its direct cost. Many rewards to the individual researchers should be offered as incentives to successful efforts. These men may be in a college, but they are still human. Then, when the college researchers have discovered some new thing in science which is important, but offers no practical application as far as they can, in their disinterest, see, they might call a clinic of the research directors of certain industries who would observe the phenomenon. The directors, having put their fertile imaginations to work, would get the scent of profits and go back to their shops in full cry on practical research and development.

Every avenue should be utilized to bring industry and the colleges together through meetings of their personnel and through common aims and undertaking. We can have more and better practice schools, more seminars, more graduate schools, part time and full time. Industry can give every able professor a laboratory and time to publish his findings. Money spent on these things will return again as tangible dividends, as well as doing an intangible good for our country.

We may eventually vision the time when industry and education are so closely related and so interwoven that it may be difficult to tell whether an individual is a worker in industry, or a faculty member in college, or whether he is a teacher or a student, and as a matter of sober fact, he may be all four over a year's time.

Industrial Science and Community Health

CHARLES L. DUNHAM

Chief, Medical Branch, Division of Biology and Medicine, U. S.
Atomic Energy Commission, Washington, D. C.

I INTERPRET the term "industrial science" as properly including all the activities of modern industry which exploit our current fund of scientific knowledge as well as those activities of industry which are making very real contributions to the fundamental sciences.

It is interesting to observe how industry, which for many years was largely content to make use of the knowledge acquired in university and other non-industrial laboratories, has grown impatient with the rate of increment of basic scientific knowledge and has established within its own laboratories facilities for developing fundamental knowledge in the sciences. Furthermore, finding that it cannot hire all the desirable talent for this sort of research, industry has taken to supporting fundamental research at the university laboratories.

With this exploitation of modern science has come quantity production and handling of new elements and complex chemical compounds. Some have obvious and readily demonstrable toxic properties, while others like beryllium oxide are more subtle in their action and hence are more difficult to test for potential toxicity to human beings. These developments have challenged to the utmost the ingenuity of the toxicologist, the industrial hygienist, and the industrial physician.

NEW HAZARDS AND NEW RESPONSIBILITIES

Industrial science has made it possible for industry to produce new products and better and cheaper products, but frequently in so doing it has created new hazards for the workers, the consumer, and the surrounding industrial community. Consequently, industrial science, while it has made great contributions to society and to the economy of the nation, has at the same time incurred an obligation to recognize the dangers inherent in handling certain of these new materials and to devise effective methods for assuring that the workers and the public are not injured by them.

The Atomic Energy Commission and its industrial contractors as well as its major university contractors such as the University of California and the University of Chicago have been keenly aware of this obligation which arises wherever new materials and new processes are developed. I speak for everyone concerned with health protection in the atomic energy program when I say that it has been and will continue to be an extremely difficult task to keep up with the problems tossed in our lap by the physical scientists.

Industrial science in the United States has come a long way since Benjamin Franklin claimed that "West India gripes" was lead colic, the result of drinking Jamaica rum which had been made in stills with lead heads and worms, whereupon the Massachusetts Legislature prohibited their use.

Today within much of industry the industrial medicine and industrial hygiene programs are actively seeking to anticipate possible hazards rather than to wait for someone to be injured before taking positive action. However, as recently as 1910 a prohibitive tax had to be placed on phosphorus matches in order to prevent injury to workers. Today, with the advanced state of development of the industrial health sciences such a method of controlling a hazard is unthinkable.

INJURIOUS EFFECTS OF INDUSTRIAL PROCESSES

You are all quite familiar with the advances made in preventing occupational disease as it might affect the health of individual members of the community who work in a given industry. Consequently, I will pass directly to a discussion of some of the more far-reaching effects of modern industrial science and industrial organization on the health of the community. It is axiomatic that certain wastes from an industrial operation may have an injurious effect on people living in the adjacent area. The effects of unfavorable meteorological conditions in the presence of a concentration of industries which normally produce relatively unimportant atmospheric pollution was graphically demonstrated by the Meuse Valley fog catastrophe of 1930 when 63 persons died in a 48-hour period. Likewise, the Donora smog disaster at Donora, Pennsylvania, in which 20 deaths occurred dramatized the potential hazards of air pollution by industrial wastes. The cause of this episode was apparently an accumulation in the atmosphere of chemical irritants plus particulate matter as a result of the weather inversion which existed in that part of the country at the time.* Other less publicized but no less dramatic instances of airborne injury to the surrounding populace have occurred.

During the 1920's there developed in a certain district of East Toledo, Ohio, what Toledo physicians called an "asthma colony."† Most of the cases lived within one-half mile of a linseed oil mill which also expressed castor oil from castor beans. Asthma occurred in this small group of individuals whenever the wind blew the castor bean dust from the plant in the direction of their homes, or if the patient had occasion to approach close to the lee side of the factory. Careful case studies including skin tests demonstrated that castor bean dust rather than flax seed dust was the cause of the trouble.

An equally fascinating but more serious problem arose in connection with the Atomic Energy Commission's program. "Beginning in the latter part of 1947, a number of persons having diagnoses consistent with that of chronic pulmonary granulomatosis as seen in beryllium workers were reported among residents in the vicinity of a commercially owned plant producing beryllium compounds. Since it was anticipated that the Atomic Energy Commission would require considerable amounts of beryllium metal and compounds in the future, it was desirable for the Commission to secure information concerning the conditions required for the safe operation of a beryllium-producing plant. For this reason, the Commission cooperated with the management of the beryllium-producing plant in question to determine the medical and environmental factors involved in the reported cases of berylliosis. An intense epidemiologic and ecologic investigation was therefore initiated"* under the direction of Mr. Merril Eisenbud of the Atomic Energy Commission's New York Operations Office.

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* H. H. Schrenk, H. Heimann, G. D. Clayton, W. M. Gafafer, and H. Wexler, *Pub. Health Bull. 306*, 1949.

† Karl D. Figley and Robert H. Elrod, "Endemic Asthma Due to Castor Bean Dust," *J. Am. Med. Assoc.*, **90**, 79 (January, 1928).

Time does not permit a detailed account of this study. Suffice that there were found living within one-quarter mile of the plant five persons with no known occupational exposure to beryllium but who were suffering from chronic granulomatosis typical of the chronic pulmonary granulomatosis seen in beryllium workers. It was estimated that the incidence of this condition in this area was 1 per cent of the population. A total of ten cases were discovered among persons living within three-quarters of a mile of the plant. These ten cases do not include any persons, members of whose families were employed in the beryllium plants and who, therefore, could have brought beryllium dust home on their clothing. To make this study complete and to make it possible to come up with meaningful recommendations with respect to future plant operations, cooperation among the following categories of persons was needed: the industrial hygienist, the industrial physician, the specialist skilled in thoracic diseases, the local physician, the toxicologist, the meteorologist, the analytical chemist, the industrial hygiene engineer, the State Board of Health, and last but not least, the plant manager and his staff. If any of the experts had been incompetent or if the plant management or the local public health organization or the private physicians had been uncooperative, this extremely important study would have been doomed to failure.

It is becoming increasingly apparent that industrial science in fulfilling its obligations as to matters of health whether of the individual workers or of the community must not only bring to bear on any given problem all the available technical skills and scientific knowledge, but in addition, to be effective, must foster a high degree of cooperation among all persons concerned.

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* Merril Eisenbud, R. C. Wanta, Cyril Dustan, L. T. Steadman, W. B. Harris, and B. S. Wolf, "Non-occupational Beryllosis," *J. Ind. Hyg. Toxicol.* **31,** 282 (September, 1949).

INTEREST OF AEC IN COMMUNITY HEALTH

The Atomic Energy Commission and its contractors are particularly concerned with control of atmospheric pollution by radioactive substances which might result from AEC operations. For instance, radioiodine with a half life of eight days gave us some concern because it can be deposited on or taken up by forage crops and later be eaten by livestock. Extensive studies of this problem with sheep as the experimental animal have been underway for several years and will give us definite answers as to how important the problem really is. Meanwhile, contamination of grazing areas has been kept to below levels which could possibly produce biological damage.

Similarly, the Atomic Energy Commission has to worry about the problem of possible introduction into water supplies of amounts of radioactivity which, if accumulated in animal or plant populations, could be injurious to them or to humans who might consume either the water or the wildlife living near or in the water.

Today the responsibilities of industry and industrial science in cooperation with medical science and the various health agencies is well understood with respect to protecting workers and the adjacent community from hazards arising out of a particular operation. In another area, however, where modern industrial know-how affects community health, the responsibilities of industry and the various local, state, and federal agencies are not so clearly defined. I am referring to the effects on a community which has adequate but limited health resources when a large modern industrial plant moves in. This situation, though it occurred occasionally in the past, is arising with increasing frequency today. It is a far cry from the days when each industry within a community began in a small way, employing only a few workers, then (and this was especially true of small communities) the industry grew with and was largely responsible for the growth of the community. If the industry grew slowly enough, no particular strain was placed on community health facilities. They expanded and adjusted to new demands as they arose. The urgency of the atomic energy program coupled with the ability of modern industry to construct in a short period of time huge installations in undeveloped areas either on the periphery of large centers or in relatively remote spots has repeatedly pointed up the problems that accompany an abrupt increase in population. These problems result from a rapid influx of construction workers, followed by a permanent but lesser increase over the original population as the plant goes into operation. Such problems are, of course, not peculiar to the activities of the Atomic Energy Commission. Community health is one of the many factors which must be considered when any new installation of appreciable size is planned which will require the work of large numbers of persons. Large personnel demands of this sort result in even larger increases in population. Estimates of the ratio of population increase to actual workers needed on a new project range from three to one to as high as five to one.

EXPERIENCE OF AEC IN NEW PROJECTS

To show how this occurs let me cite our present experiences at Savannah River and at Paducah. Though it is our policy to employ locally available personnel to every extent possible, nevertheless a substantial portion of the required skills must be brought into these areas from the outside. Furthermore, when workers are recruited locally, there usually results a requirement for replacement in the jobs where they were formerly employed. In addition, there are added service personnel requirements—the shopkeepers, school teachers, ministers, and others who come into the area to round out the usual community picture. A majority of persons coming into the area bring their families with them.

An in-migration movement usually has two peaks: (1) the construction worker peak and (2) the permanent operating personnel peak which tends to stabilize at a considerably lower level than that reached by the temporary construction workers during the construction period. It is estimated for Savannah River that construction employment will reach 36,000 while the number of operating personnel will be in the vicinity of 5400. Similarly, at Paducah the construction employment peak is estimated at 12,000 with the permanent operating force only 1600.

Community health problems of many kinds are present at the very beginning. Among these may be cited as specific examples: adequacy of food supplies such as milk (this can be a very real problem in certain areas of the United States); proper and adequate inspections of food, eating establishments, and living quarters; adequacy of potable water supplies; adequacy of sewage disposal facilities; and adequacy of the medical and hospital services to provide care for a greatly increased population. Frequently local laws and regulations are inadequate to the new needs from a public health standpoint, and the first approach must be made with the state and local authorities to correct deficiencies. This is especially true during the construction stage. If adequate safeguards are not promptly provided in the way of county or community zoning and/or health regulations, shack towns and general slum areas will tend to develop with all the serious health problems that inevitably follow.

Until the passage of Public Law 139, the Defense Housing and Community Services and Facilities Act of 1951, the federal government had no way of generally assisting in these areas where all sorts of problems were created through establishment of new federal installations. This legislation which became law on September 1, 1951, is patterned, to some extent, after the Lanham Act of World War II. Public Law 139 provides for liberalized mortgage financing for housing required in areas which are designated as critical defense areas. It provides that the Housing and Home Finance Agency and the United States Public Health Service can provide assistance to local communities for community facilities and services that are required as a result of the in-migrant workers that have come into the area to work on the federal project. Community facilities and services assistance includes hospital and medical facilities.

Even if sufficient funds were appropriated and available for providing all the forms of assistance designated in the act, there would still be the problem of changing and disrupting normal activities. Close working relationships must be established with the regularly constituted authorities and specifically with those having responsibilities for health and hospital services.

INDUSTRIAL HEALTH SERVICES

Industry itself pioneered in providing adequate health services for its employees. As early as 1868 the Southern Pacific Railroad hospital department organized the first major industrial medical care prepayment program. This was financed jointly by the employer and the employees. In 1869 the first Southern Pacific hospital was opened in Sacramento, California. Today this program renders complete service through a full-time staff at the Southern Pacific Hospital in San Francisco and through arrangements with physicians along the line. In 1887 the Homestake Mining Co. at Lead, South Dakota, established a company-financed medical department with a full-time staff which provided complete medical service to employees and their families.

This involvement of industry in the care of non-occupational illness among its employees and their dependents appeared first in connection with installations such as mines and lumbering operations in remote areas and among the western railroads which were serving sparsely populated areas. The plans which developed represented all degrees of participation by industry. In some instances the company bore the entire cost, including construction of and staffing the community hospital. In others the employees bore the major cost of the plan. It is interesting to observe how the tendency for industry to assume more and more responsibility for non-occupational medical care has grown. Non-occupational sickness and accident benefits are fast becoming standard items in collective bargaining agreements. The real dividend to industry in these plans is improved employment efficiency and morale. Those industries (by industry I mean both employer and employee) in which such benefits involve important amounts of money are consequently going to take an interest in the standards of medical practice and in preventive medicine activities as they affect employee efficiency and morale. Where prepaid complete medical care programs are involved, the effect of industry on the actual practice of medicine is already apparent.

In conclusion then one can say that industrial science has led the industrial hygienist and the industrial physician, to say nothing of the public health agencies concerned, a merry chase. The industrial physician and the industrial hygienist are, for the most part, doing an excellent job of keeping pace with the new developments of industrial science. In spite of new hazards and the increased number of workers, occupational disease is better controlled than in the past. Industrial science in a true spirit of cooperation is increasingly conscious of its responsibilities toward control of hazards that might affect the workers in the plant or the community in which they live. The establishment of such huge installations as the AEC Savannah River project produces a host of acute problems which affect community health and require the utmost in cooperation among all concerned. Industry, both management and labor, through the various medical service plans now available is already exerting an influence on community health. It is inevitable that as the industrial potential of our nation continues to increase, industry will play an even greater role in determining the course of medical practice and preventive medicine in this country.

The New Industry and the Community

ROBERT A. NEARY

Public Relations Department, Aluminum Company of America,
Pittsburgh, Pennsylvania

As I conceive this subject, it is concerned with an appraisal of the impact made upon a community by the introduction of an industrial operation. The industrial enterprise with which I am associated has certainly had a fair measure of experience in locating, building, and operating industrial plants in communities of varying types, ranging from highly industrialized metropolitan areas to rural communities previously unacquainted with any aspect of industry.

For example, during and prior to World War II, our organization on its own initiative and later at the request of the government built and operated more than twenty plants to produce and manufacture aluminum and aluminum products. The plant sites were determined by government agencies and were located throughout this land, on both coasts, in the Gulf area, the arid plains, and the rich agricultural centers. We were responsible for the construction and operation of the plants in those locations no matter what problems may have resulted from locating in those specific areas—and there were problems. The success of our effort is best attested by the fact that all but a few of those plants built during the war period have since been continually operated by other private manufacturers.

Today industry is embarked upon another expansion effort. The experience gained in years past should stand in good stead, as we meet similar problems and work toward what we hope will be equally satisfying solutions.

APPRAISING THE PROBLEMS

What is this impact upon a community, when industry locates a plant there? What are some of the problems that confront industry and the community? How are these problems solved to their mutual satisfaction? What are some of the benefits that come to the community through the location and operation of an industrial plant there?

I think we may assume that, prior to the selection of a plant site, management has investigated to its satisfaction the availability of required raw materials, that any question as to the equitability of freight rates and adequacy of labor supply has been satisfactorily answered, and that the geographic location of the plant does not place it at a disadvantage in so far as proximity to the consumer market is concerned.

Assuming then that all these questions have been answered, what are the other elements that must be thoroughly investigated by management as it proceeds to design, construct, and operate the plant. Experience has shown that if work is to proceed with a minimum of delay, confusion, and possible harm to company-community relations industry must appraise the adequacy of such community facilities as housing, transportation, sanitation, education, hospitals, public health and safety, the availability of such necessary utilities as water, fuel, and electricity, and even concern itself with the scenic aspects of the area as well as with climatic conditions.

In appraising these factors, management must do so not only with an eye to their sufficiency to permit the most efficient plant operation. It must also bear in mind that its use of these facilities may have pronounced effect upon use of the same facilities by other residents among whom will be included personnel of the plant operating force.

In its appraisal then, management must be prepared to take such cooperative steps as will be necessary to relieve any possible hardships resulting to the community through the use of the facilities by the plant. I should like at this time to describe some of the situations that we have met and offer as cases in point certain means by which they may be satisfactorily handled.

EARTH SCARS

Let us consider, for example, the situation arising where a plant operation is located at the source of supply of raw material. Let us say that this raw material must be mined, as in the mining of ore, and that this ore deposit borders the community itself. When ore is mined by the open pit method, great scars are carved into the surface of the earth, leaving behind unsightly excavations and mountainous piles of waste along with denuded forests. None of these can be said to add to the attractiveness of the site; in fact, they may impede future development of the area. Experience has shown, however, that with a little planning and physical effort, these areas can be rehabilitated through soil conservation programs and reforestation projects to alter their unsightly appearance and topography so that they are restored to something approaching their original attractiveness.

In a location where one company conducts a mining operation, such restoration measures as these have been undertaken so that what would otherwise be a comparatively desolate and barren landscape is once again assuming a mantle of forest and vegetation created by planned reforestation and landscaping projects. When such remedial steps cannot be taken directly at the affected area, then the company may energize a program to improve the surrounding area so as to offset the unattractive aspects of the mine area proper.

WATER POLLUTION

At this same location, it was discovered a few years ago that water runoff from the mountainous piles of waste resulting from ore mining was causing a stream pollution condition. Working with the state conservation agency, plant chemists determined that rain water streaming from these waste piles carried with it acids that were destroying fish and vegetation in the streams below. Investigation showed that by impounding these waters for a period of time the acid content could be dissipated and subsequent seepage into the streams would produce no ill effects upon the fish and vegetation in those streams. Miniature lakes were then dredged at the waste areas and the water retained in them to be disposed of by natural evaporation and slow seepage. As a result, the pollution problem no longer exists. The fish population is thriving, the sportsmen are just as happy as ever. It was simply a matter of industry recognizing a problem created by its necessary operations and taking steps to correct it.

TRAFFIC AND TRANSPORT

In other more urban areas, traffic and transportation facilities can become the hub of some rather troublesome situations. For example, in an urban area where a company conducts around-the-clock operations and shift changes are a necessity, increased traffic that results when shifts are changing may cause merchants, pedestrians, and police agencies alike to curse the day that an otherwise beneficent industrial operation chose their community as a plant site. Public carriers may be overcrowded and delayed in their schedules to accommodate commuting workers. Roadways may be jammed at plant entrances and exits with the autos of workers coming to and going from their jobs. Near-by curbsides may be lined solidly with the parked autos of plant workers busy inside the plant gates. It can be an unhappy situation unless company and community officials study the situation carefully and seek to solve the problem to their mutual satisfaction.

The solution may call for the staggering of starting and quitting hours for plant workers, the development of a private parking area for the cars of plant personnel, enactment of ordinances restricting the travel of auto traffic over certain streets and highways at peak traffic hours, the increase of carrier units by the bus and trolley organization serving the plant area during the periods of heaviest use by industrial plant workers. Any one or perhaps all of these may be required to relieve a condition which could seriously harm the efficient operation of a plant and detract from the further development of the community.

HOUSING

The question of adequacy of traffic routes to the plant site may have some interesting ramifications. Particularly in an around-the-clock operation, it is vital that routes to the plant be available to workers with a minimum of delay at any time. If only one route is available, any obstruction to the use of that route could conceivably hinder the operation of the plant. As a result it may be necessary for additional thoroughfares to be constructed. Or it may mean that plant personnel should reside in areas close to the plant site. This latter alternative implies, of course, that desirable housing is available in that area. For example, I know of one situation where a plant site is located on a promontory approximately five miles distant from the community in which some workers live. Workers travel to the plant from their residences in the community by means of a causeway spanning a two-mile stretch of shallow water. Should that causeway be destroyed, or its use impaired for any reason (e.g., by hurricanes such as have occurred in years past), the highway distance between town and plant site is no less than 100 miles!

Consequently, additional houses are to be built on acreage adjoining the plant site. Along with the houses a recreational center is to be constructed, so that residents here will have a self-sufficient community of their own. This development is not the first housing project undertaken by the company in this area. One of the first developments in connection with the plant was the building of a group of houses in the older near-by community. The houses built by the company were sold only to plant staff personnel, but additional plots in the improved development were offered for sale to persons other than company personnel. Today some of the most elaborate homes in this development are those built and owned by other citizens of the community.

The problem of housing employees has several aspects which industry finds interesting, to say the least. In many instances, housing adequate to accommodate a sudden influx of plant employes may not be immediately available. Yet to obtain necessary manpower, sometimes recruited from other areas, such housing is a prerequisite. It may require that new housing projects be undertaken. Such houses, if they are to be occupied by plant personnel, must be made available to these people at prices and terms consistent with their income level. Largely this means homes priced at $10,500 or less, obtainable with a small down payment, having long-term mortgages at relatively low interest rates. If local financial institutions are unable to participate in lending ventures such as this on the large scale required, or if local contractors are disinclined, or unable, to tie up money and materials in such a program unless a quick return on their investment may be realized, the company may itself build and sell or rent the homes. Or the government, basing its decision upon a survey of the situation, may nowadays have the area declared a "Critical Defense Housing Area." Under such a designation, federal restrictions on credit are relaxed in order to permit the sale of homes with lower down payments, with longer mortgages, and at low interest rates. In some areas resistance to such a designation may be encountered on the part of local interested persons who may be unable to participate in the program or who may consider the terms unfavorable for participation. It is only by a careful explanation of the situation and its true seriousness to the long-range program of community development that this resistance may be overcome.

I might also mention here the steps that a company may consider taking in order to alleviate discomfort resulting to personnel from temperature extremes, the presence of excessive insect and reptilian life, or scenic barrenness.

Industry can and has in many cases taken appropriate steps to alleviate personal discomfort resulting from climatic extremes. By incorporating into plant and office design insulating materials as well as air conditioning equipment, work areas have been made more comfortable, with consequent improvement in productivity.

With regard to insect and reptile control, industry has also in many cases embarked on programs designed to eliminate these pests and thus to remove the debilitating effects their presence can cause plant personnel.

In certain areas, a real psychological barrier may be encountered by the absence of shrubbery or foliage to soften the landscape. Personnel recruited from more verdant areas may find it difficult to adjust themselves to a landscape having none of the beauty of the garden, the grove, the lawn, and the forest. To minimize such a condition, again the company may undertake a well-planned landscaping project by which shrubs and trees that flourish in the area will be planted to add to the attractiveness of the site.

INSTITUTIONAL SERVICES

Other facilities in the community, too, when required to serve an enlarged population, may find it difficult to perform their functions satisfactorily. I have in mind the hospitals, schools, institutions such as the YMCA, community centers, police, and fire prevention agencies, churches, and other institutions. With their facilities swamped by an enlarged demand for services, their only recourse is to undertake expansion programs by which to serve the community better.

In the case of hospital and school building expansion programs, the company may be called upon to assume an extra proportionate share of the cost involved in such programs. For it to do so upon a just basis requires that each need be judged by its individual merits, for no blanket policy can always successfully be applied. In certain areas and under certain conditions the company's tax payments take care of the company's obligations. The company may decide to provide additional assistance through the contribution of equipment to existing facilities or new facilities. Whatever action is taken, I repeat that the need must be considered on the basis of its own merits, if the company is to give just and equitable assistance.

EVALUATION OF BENEFITS

It would perhaps appear from what I have said here that the arrival of a new industrial enterprise in a community is no more than the occasion for a tremendous number of problems both to the community and to the company. Such is not the true case. Although it may appear that we have been discussing here how industry discharges its responsibility to society, we have no less been discussing, too, how industry serves to develop and enlarge and improve the very society of which it is a part.

In all the elements of the community in which the industry is operating, the effects of those operations are sensed and evidenced in some way. Economically and culturally, industry's presence is felt throughout the community. Whether that presence is judged to be good or bad by the community depends upon the manner in which we conduct our presence and make known to the community the facts of our daily existence there.

One means by which the facts of our existence may be described to our community neighbors is the Open House through which community neighbors may see for themselves the nature of our operations and be informed of our contributions to the general welfare. There is no better way to allay unfounded fears and misconceptions concerning our operations than by inviting our neighbors to our operations to see for themselves the tools with which we work, the products we make, the conditions under which our employees work, and to learn at first hand the policies that guide our daily efforts in our business life.

One other aspect of the impact of an industry's residence in a community, which I have not yet mentioned, is the introduction into the community of new residents bringing with them an active interest in helping the community grow and prosper. Personally, or as representatives of the company, some of these will, perhaps, have the opportunity to assist in civic undertakings. In such capacities they may have the opportunity to speak for the company in explaining to their associates the policies by which the company is governed in the conduct of its business life as that conduct affects community life. Similarly, as community representatives, they may acquaint the company with the policies and philosophies by which the community is motivated in its various civic undertakings. Thus they may help relieve, by their words and their actions as company representatives and private citizens, any potentially difficult situations that could arise from what may wrongly appear to be conflicting interests of the company and the community.

So that some idea may be obtained as to just what are some of the economic benefits resulting from an industrial plant's location in a community, I would like, at this point, to quote some statistics recently gathered for one area where we operate one of our plants. We began plant construction there in 1948. Operations commenced there early in 1950. Here are some of the results of our moving there. In 1940 the population of the community was 2069; in 1947 it had increased to only 2200; in 1950 it had grown to 5062. In 1947–48 there were 78 business establishments; in 1951 these had been increased to 185. In 1946 the county in which the plant is located had 1388 motor vehicles registered; in the year ending 1951 there were 3714. In 1945 assessed valuation of the county was $7,675,821; in 1950 this had increased to $19,094,688. The income of the county in 1946 was $3,216,000; in 1950 it was $8,272,000. Bank deposits in the same period grew from $2,493,000 to $7,125,000. Retail sales increased from $1,967,000 in 1947 to $5,551,000 in 1950.

During a longer residence in another area, the county in which our company conducts a sizable operation has advanced from one of the lowest ratings in the state in so far as assessable wealth is concerned to a present-day position in the first ten. Actually, the county's standing has improved from eighty-fifth among 95 counties in 1913 to sixth in the same number of counties today. I do not contend that this increase in material wealth has resulted entirely from the presence of an industrial operation in an area, but certainly it is conceivable that that operation has contributed to the improvement in the situation.

Material gain is not the only influence we may exert in these trying times. As industry discharges its responsibility and gives evidence of the desirability of its continued existence as a freely competitive element of society, so must it take steps to assure that its function is understood, that its benefits are recognized by the people most closely associated with it, its employees and its community neighbors.

Acting as a good citizen and a good neighbor—and being known as such—industry will gain for itself the active support of its fellow Americans in the mutual effort to keep America progressive and free.

Industrial Science and Its Public Relations

G. EDWARD PENDRAY
Pendray & Company, New York City, New York

THE American astronomer Simon Newcomb once advised people who were troubled, confused, or worried by the world to mount a hill somewhere in the country on a clear night and look at the stars. In the velvet blackness of the starry night the common things of life, which at other times seem so near and so important, take on new perspective. The human spirit gains new understanding and strength.

Similarly, we can sometimes get useful perspective by taking an objective look at the human universe—seeing the whole panorama of it and placing ourselves and our works where we properly belong in that vast complex of thoughts, actions, relationships, attitudes, beliefs, desires, memories, and anticipations. It is a world as vast in its way as the starry universe, as mysterious and remote, as oblivious of us as persons and of our small designs. Yet unlike the galaxies of space, the cultures and societies of earth are the matrices in which we and our activities are molded into what they are.

Now, when American industrial scientists so view the social and cultural scene, what do they perceive? On every hand, they see the fruits and impact of their own handiwork. Our culture appears as a thorough creature of technology. There seems to be no least aspect of human action that is not in some way affected by it.

Whether this is "good" or "bad" is not for us to judge. It has become; it is. Obviously the public likes the products of industrial research. The clamor for more of the same seems virtually endless. As a consequence, technologists these days are seldom seriously concerned about the future of industrial research. They take for granted that it has been so securely planted, its results so wholeheartedly accepted, that any progression of society could hardly be imagined that did not include more of it, rather than less.

But is this assumption either accurate or safe? Underneath, is the human animal of today so very different from his ancestors in their time of superstition, isolation, and barbarism? Has the human been transformed by technology into a wholly enlightened creature? Or is he what he always was: a savage still, even though he has replaced the spear with the bazooka, the hunting knife with the supermarket, and the oxcart with the Cadillac?

However much we might like to think he has changed, the evidence for it in history, politics, and sociology is not very strong. The teachings of psychology and anthropology seem to bear out the view that man is just about the same basic stuff he always was. He has new clothes, new toys, a new vocabulary; but he is still the same old Adam.

RISE OF INDUSTRIAL RESEARCH

Now of course that is not very surprising. For science, even if you trace its beginnings back beyond the Industrial Revolution, is so young it has hardly had time to make any real changes in the fundamental man—assuming for a moment that it could. And industrial research as we know it today is newer still. It is virtually a development of this generation.

In 1915 there were probably fewer than 100 industrial research laboratories in this country. Fewer than 1500 research workers were employed in them. By 1920 the number of laboratories had increased to 300; the number of scientific workers to about 4700. In 1940, the number of industrial research laboratories was 2300; the number of research workers 36,000. But by 1950 the industrial research laboratories exceeded 2700, industrial research workers numbered 70,000, and the total personnel of these laboratories, including clerical workers and maintenance people, was nearly 175,000.

Thus, from just before World War I until now, a time span of 36 years, the number of industrial laboratories in the country increased more than twenty-seven-fold, and the number of industrial research workers increased by forty-seven times.

What has produced this rapid, almost explosive growth of industrial technology?

There can be no simple answer, except perhaps to say that Western man was ready for it; his thinking, his culture, his real or fancied needs, the political and economic climate in which he lived was ready for it, and it came. This of course is to answer the question with a generality that really answers nothing. But it brings our attention to an important aspect of the matter just the same.

In the 100th Psalm there occur these lines:

> Be ye sure that the Lord He is God;
> It is He that hath made us, and not we ourselves:
> We are His people, and the sheep of His pasture.

No sacrilege is meant; indeed the parallelism may be more real than at first seems to be true; when these lines are paraphrased and applied to industrial research and industrial research workers.

It was the people who made them; not they themselves. The people so far have been pleased with the results of their work and have created a market for their goods and services. The corollary is that upon the continued pleasure of the people depends the future of industrial research. The same is true, of course, of law, medicine, public relations, accounting, and any other profession, trade, business, organization, or economic activity. In our culture, the people have brought them into being. And with the people lies the daily power to provide them with growth, stagnation, or extinction.

If this too much belabors a fairly obvious point, I beg your indulgence. For all too often leaders, organizations, and institutions behave as though they thought this truth untrue—as though somehow they believed themselves creatures of their own will and cleverness; existing and growing in spite of the public; or by manipulating it, or by pursuing their activities oblivious of it. There are, I think, some research administrators and their associates who have seemed to hold this philosophy too; men whose direct contacts with the public have been cool and distant almost to an offensive degree, who have thus defied, unthinkingly, the very power that brought them into professional being and alone can maintain them there.

Certainly many businesses and industrial organizations have been guilty of this mistaken view of themselves and their place in the social structure, some to their great sorrow. For, as the Lord giveth and the Lord taketh away, so do the people. It requires no great exercise of hindsight now to perceive how much of the destructive business baiting that has changed the economic scene in this country in the last twenty-five years resulted from the failure of businessmen and industrialists a generation ago to understand the public and their relation to it—and to give accounting for their stewardship with humility, instead of arrogance.

THE RISE OF SCIENCE

Now, as regards science and its fruits, what has been, and is now, in the public mind? We had no such thing as the public opinion poll in medieval times, but if a nodding acquaintance with history does not lead us astray, we may imagine that such a poll would have disclosed little interest then in electric refrigerators, jet planes, or plastic bath mats, even had they been available. It was a time when people believed wholeheartedly in the reality and importance of the supernatural. Society lived not for this world, but for the next. That type of society lasted for a thousand years and more. Gradually it wore out.

Then came the new Awakening. The ancient civilizations of Greece and Rome were rediscovered, and with them, philosophy. New worldly interests quickened the search for knowledge. Nature began to be studied for her own sake. Invention, science, and industry followed, and with them came social changes in the direction of human liberty and economic freedom which have finally flowered on our continent in what we call the American system, a socio-politico-economic system such as the earth has never seen before.

During that time how did the public learn about science and its fruits? The fashionable word just now is communication. How did science and invention and industry communicate with the public? Primarily of course through salesmanship, at first through word of mouth and demonstration, later through printing and commercial advertising, still today one of the most important educational media of the people.

SCIENTIFIC WRITING

Along with the marketing of material inventions there came a new philosophy, the philosophy of science the wonder worker, the new art that "could grasp the sorry scheme of things entire and mold it nearer to the heart's desire." By understanding nature, so belief went, men might ultimately control it, and thus control their destiny as well. This was the philosophy of the scientist. It was communicated to the people in numerous ways: through lectures, through books, and pamphlets, through such novels as those of Jules Verne and later of H. G. Wells. In the nineteenth century and the early part of the twentieth, science seemed synonymous with progress. The direction of man's development seemed ever upward. Technology would someday free humanity from every shackle: economic, social, even biological, and intellectual.

In our own day, beginning in the middle 1920's, a new kind of journalism appeared, the so-called reporting of science for newspapers and popular magazines. It is no coincidence, I think, that the period of the rise of special science reporters and writers coincided with that of the greatest growth of industrial research. It would be going too far to suggest that either was the "cause" of the other. Rather, they both arose from the same underlying phenomen, the great public interest in science and technology, the enormous popular hunger on one hand to learn more about it, and on the other to enjoy more of its fruits.

CHANGE IN SCIENCE OUTLOOK

These twin hungers are still with us. Newspapers, magazines, radio, and television carry surprising amounts of popular science material. Science books sell well. The desire to learn about science is as strong or stronger than ever.

But when we look at the content of the articles and news stories about science these days, we note a disturbing change in the philosophical climate. Twenty years ago, when some of us who were then science reporters were young, each science story was a wondrous bulletin of new progress toward greater understanding for the common good. We were reporting the unfolding story of the atom as though that tale would end with blessings for everyone. We were following the development of rockets and jet propulsion with a view to giving man new far horizons and speedier wings with which to reach them. We were following the advances in bacteriology, the filterable viruses and biology, thinking that the new knowledge of these would free mankind from disease and pain, even from old age and death itself.

Now these stories, unfolding farther, have taken on a wry and forbidding taste. The atom, which was to set man free, now appears fit principally to set him free from life itself. The great forces of science and technology, abetted by government, are seen as straining every effort to find new, more frightful ways to kill, maim, and destroy. Stories we read about science's accomplishments fill us with misgivings, and underlying almost every one are hints of even more sinister and frightful things to come.

Now where is the symbol of the kindly, selfless, inquiring scientist; his mind deep in the workings of nature, his eyes on mankind's future good? The man people seem to see in the laboratory today wears a gas mask. He manipulates his radioactive brews by remote control, watching them through mirrors, like Perseus dealing with the gorgon Medusa. He speaks the language of Mars; his heart is an atomic pile; he appears to have the soul of an IBM machine.

In a time when the country is fully aware that it must defend itself against a ruthless foe, when science can so demonstrably come to its rescue, is this picture of the modern research technologist so bad? I think it is. For the long run it surely is—probably for the short run too—because nobody loves a killer, or trusts him far, even if he does his killing on our behalf.

What people found so attractive in science in the older days was not alone the material benefits of the scientific age. The advance of science used to give them a feeling of going somewhere, a sense of leadership and progress. Where is that feeling of progress today?

Now, are there any real signs that the alleged bad symbol of the modern research scientist is hurting anything?

It is hard to tell in human affairs where the big turning points come, except in retrospect. But there are certainly some signs that public attitudes toward science are undergoing change, and not for the better. Take the present well-known shortage of scientific and technical graduates. It is not caused wholly by the accelerated demand for technical people brought about by war. No small part is due to the fact that young people no longer seem attracted to science as a career.

Recently Dr. M. H. Trytten estimated the number of Bachelor's degree graduates to be expected in all the sciences by years through the spring of 1954, as indicated by the numbers of undergraduates enrolled in science courses today. His series starts with 1950, when there were 75,000 science graduates. In 1951 the number dropped to 47,000. In 1952, the number of graduates will be 36,000; in 1953, 33,000; and in 1954 only 29,000.

"These figures," he reports, "are probably on the long side, since every indication which has become apparent in the past two or three years reflects a reducing interest in the sciences and engineering on the part of entering college freshmen."*

How can we explain it? Lawrence P. Lessing tried it as follows in *Fortune* magazine, September, 1951.

> The U. S. came out of the last war with an intelligentsia tired of the mechanical riot, the overpowering complexity and potential destructiveness of science, and ready to call for a slowdown in favor of the more peaceful liberal arts. This was heightened by attacks upon science and scientists, both political and professional, and by attempts to reinstate medieval classic studies to their old position of dominance.
>
> Yet the stark fact is that all postwar warnings of an overemphasis on the physical sciences or an oversupply of scientists and technicians have not only been unwarranted but harmful, and the nation must now deal with a malaise that is running deep.
>
> While science and engineering have been held up as less and less honorific pursuits, society has been directing them ever more thoughtlessly and persistently to destructive ends. These are not the ends to fire the imagination of youth.

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* M. H. Trytten, "Government Agencies and Policies," address delivered at Engineering Manpower Convocation, Pittsburgh, Pa., September 20, 1951.

There is much evidence that Lessing and Trytten are right. More could be brought to bear, but I do not believe it is necessary to underscore the point further. Organized scientific and research bodies are becoming increasingly troubled at the trend of events and are casting about for a solution. The need for science and technology to look to its public relations is more evident every day. The question no longer is whether some program should be undertaken, but what the program should be and how it should be carried out.

It is also evident that the problem is no mere superficial one, that can be dealt with by means of a few publicity releases and a popular lecture or two. Experienced professional public relations people know that something equivalent to Newton's second law of motion operates in matters of this kind. To counteract a force in society, you must meet it with another force of equal energy. You cannot neutralize or deflect a strong dynamic social movement with nothing but a mimeograph machine, any more than you can stop a V-2 rocket with a feather duster.

What is needed, then?

First, there must be a general determination among research men to take a new attitude toward the public, to consider themselves truly its servants, to whom they must and should report.

Secondly, a strong, unifying idea is needed, dramatic enough to seize popular attention and imagination, appealing enough to counteract the undesirable image of science now growing up in the public mind.

Thirdly, a program is required for communicating this idea effectively and persistently, among research men themselves, among the employees and families of research laboratories and institutions, among the communities where research laboratories operate, and to the general public. This program of communications must take full advantage of the magic of the idea, the illuminating nature of research in all aspects of human affairs, and the natural human interest in new things and new ideas, particularly as they affect the future.

As to the first requirement, I think we have seen abundant signs in recent months that industrial research people are developing new values in their thinking about themselves, their communities, and the public at large. In September, 1951, the Fifth Annual Conference on the Administration of Research, meeting at Ann Arbor, Michigan, gave a full session to considering the public relations of research. In November the Industrial Research Institute devoted its entire three-day annual meeting to various aspects of the subject.

Shortly after the latter meeting, the research division of Pendray & Company made a small survey to learn what, if anything, industrial laboratories themselves are doing about employee, community, and public relations. Fifty laboratories were queried, ranging from small to large, representing a good cross section of the various major kinds of industry. More than half told us they already had, or were in process of setting up, some sort of organized community or public relations work.

As to the second requirement, a unifying dramatic idea. This will take some work and thinking, but the elements of it may already be near at hand. The new goal for science and research could well be fashioned on a foundation of the old: the magical idea of human progress through science and technology. Let us broaden it to take in all the social and psychological phenomena as well as the physical, all the human problems of the race, rather than just the material ones. Great areas still lie open to research like a fallow, mysterious, and unknown land awaiting the Newtons, Davys, Galileos, and Rutherfords of the scientific age to come. Let us here and now renew our own vision of this future world, and our faith in it.

Next, we must communicate the power of this idea among ourselves and to the world. We need all hands to take their proper part: the professional societies, the technical and scientific schools, the industrial companies based on technology, the research scientists everywhere.

But we need to start somewhere. Where can we do it best?

I think a logical place is in the laboratories of industry. For daily, despite what we may read in the papers, science, technology, *and* the American system of industrial enterprise are forging new bridges to a better future. It is true that war work occupies a great deal of our energy; it must if we are to survive. But there is hardly a laboratory in the country where peacetime projects are not going forward too, where developments vital to the future of mankind are not emerging along with guns and missiles. Let us begin to emphasize those things in our own thinking, in what we say to others, in what we write, in what we release for publication.

PROMOTION OF PUBLIC RELATIONS PROGRAM

This is a crusade that many an industrial company could well take up, to its own benefit as well as that of society. Science is a perennially fascinating subject. Yet for some strange reason relatively few companies are really doing a first-rate public relations job with it. You can almost number them on the fingers of one of your hands. The others perhaps do not yet understand the value of the research story they have to tell, or possibly do not yet know how to tell it in terms of interest to the public. To be sure, it is not easy. The interpretation of science is a subtle and exacting art, as anybody knows who has tried simultaneously to satisfy the scientists and interest the public. Yet it can be done, as those who have been successful at it clearly show.

It seems to me this program should also be taken up in a major way by scientific and engineering organizations, perhaps spearheaded by our own American Association for the Advancement of Science. By virtue of its size and the scientific areas it represents, it is in the best possible position to give this leadership. But here again, it is a *public relations* program that must be undertaken, not a publicity campaign. If the program is to succeed it must be based on ideas and action, not words. And whatever is undertaken must be commensurate in magnitude and significance with the importance of the task.

In any case, the job needs doing. The time to start is now. Every industrial scientist can properly consider himself a vice president here, a vice president in charge of public relations for science and technology. It is a job in which everyone has a part. The public's attitude toward science and research is shaped in some measure by every contact a research man has—with his associates, his neighbors, his community, with writers and opinion leaders of all kinds, in virtually everything he does and says.

The rewards for good relations with the public are great. They are no less than the continued growth and influence of science and technology in human affairs.